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# EFFECTS OF CROPS ON THE YIELDS OF SUCCEEDING CROPS IN THE ROTATION, WITH SPECIAL REFERENCE TO TOBACCO [1]

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## INTRODUCTION

The fact that continuous culture of any particular crop on the same soil quite commonly results, sooner or later, in decreased yields must have been observed in the earliest days of agriculture. Solution of the problem as to the cause or causes involved, however, has proved to be decidedly difficult. Macaire (*15*),[2] in 1832, remarked that in the broadest sense the rotation of crops is as old as agriculture itself, having come into practice as a matter of necessity, while he further stated that the definite formulation of a theory of crop rotation in the early part of the nineteenth century marked an important advance in the science of agriculture. Two principal theories have been offered in explanation of the unfavorable influence of one plant on another of the same or different species which is frequently observed when the two are grown in association or when the one occupies the soil in advance of the other. The oldest of these theories, involving the idea that a plant may excrete through its roots substances capable of exercising varying degrees of toxicity with respect to itself and other plants, was developed mainly by De Candolle (*3*) in his Physiologie Vegetale, published in 1832. Clements, in a recent monograph (*4, pp. 144–162*), has given a comprehensive review of the fairly extensive literature on the subject of toxic exudates of plants and the rather closely related conception of soil toxins emanating from plant débris, so that for present purposes it will suffice to refer very briefly to these theories.

De Candolle based his theory of toxic root excretions largely on the results obtained by Macaire (*15*). In maintaining well-developed plants in pure water for a time Macaire found that the water acquired toxic properties and contained substances which were regarded as plant excretions. De Candolle considered that plants tend to affect the soil unfavorably for other plants of the same species, genus, or family, and drew a distinction between this sort of unproductivity of the soil and general soil exhaustion affecting all crops and due to lack of plant food. He also stated that dead plant material may be either harmful or beneficial in intermediate stages of decomposition, but is generally beneficial when more fully decomposed. Macaire suggested that the very ancient practice of fallowing or resting the land really involves a rotation of cultivated crops and adventitious vegetation, and that replacement of weeds by useful crops in the rotation is to be regarded as a distinct step in the progress of scientific agriculture. In the light of the results of cropping tests presented in this paper, one needs to be fairly specific both as to crops to be used and conditions under which they are to be grown in putting into effect this seemingly logical suggestion of Macaire.

De Candolle's theory of toxic root excretions soon gave way, at least for a time, to the "plant-food theory" developed by Liebig, according to which soil productivity may be measured primarily in terms of the available supply of plant nutrients. Differences in the effects of crops on the yields of succeeding crops would thus be explainable on the basis of differences in the kinds and quantities of plant nutrients removed from the soil by the different crops. For the greater part of a century this theory has largely dominated field experimentation in soil productivity, though it has as a whole undergone considerable modification during this time. There can be no doubt as to the fact that the supply

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[2] Reference is made by number (italic) to "Literature cited," pp. 1132.

of available nitrogen and mineral nutrients in the soil is one of the important factors in crop yields. On the other hand, inability of investigators to arrive at a satisfactory basis for generalization in the use of fertilizers, after an enormous amount of experimentation, has brought about a realization that there are other factors in soil productivity of fundamental importance. Thus, at the beginning of the present century there was a revival in modified form of the theory of soil toxins wherein these toxins are considered as of vegetable origin but not necessarily consisting of excretions of the living plant.

Among the leaders in the development of the newer theory of soil toxins were Bedford and Pickering in England, and Whitney, Cameron, and Livingston in this country. While Liebig was developing his plant-food theory other investigators were pointing out that Macaire's supposed toxic root excretions might well originate merely from exfoliated root material, and, in fact, De Candolle himself, as already stated, had included consideration of the effects of plant débris in outlining his theory. Bedford and Pickering (*1*) made an extended study of the harmful effects of grass on the growth of fruit trees, and also made observations on many other plants. Whitney and Cameron (*20*) and Livingston, Britton, and Reid (*14*) found that certain unproductive soils as well as their aqueous extracts contained substances toxic to plants, while their toxicity was reduced by addition of certain forms of organic matter, oxidizing agents, and other chemicals, including plant nutrients. Schreiner and his associates (*16*, *17*) isolated from soils several organic compounds which were found to be toxic to plants.

Mention is made also of a recent extension of the theory of soil toxins to include the action of such inorganic toxic substances as soluble salts of aluminum and iron, more particularly as a feature of the soil condition spoken of as acidity. There has been considerable controversy between adherents of the newer theory of soil toxins and those favoring the plant-food theory, and this has brought about a great deal of valuable experimentation. In going over the published data on the subject one can scarcely escape the conclusion that in many instances investigators have gone too far in their interpretations of results obtained in reasoning from the particular to the general, while, on the other hand, some have apparently erred in placing unwarranted restrictions in their interpretations of available data. It appears that further work is needed to reach a final conclusion as to the exact bearing of these two theories on soil productivity.

In recent years plant parasitism has come to be recognized as an important factor in soil productivity. As a rule, parasitic microorganisms are more or less specific in their ability to attack higher plants, so that continuous culture of the same or closely related crops would favor development of parasitic disease and thus reduce crop yields. Many cases of this sort have been brought to light in recent years. Ordinarily the causal organism can be readily recognized, but this is not always the case, and definite exclusion of parasitism as a factor in the unfavorable influence of one crop on another is not always a simple matter. Parasitism alone, however, hardly furnishes a sufficient basis for generalization concerning the effects of crop plants on others growing in association or in rotation. Finally, while it is now known that nonparasitic soil microorganisms may greatly affect soil productivity, this fact does not seem to call for a separate theory of general applicability to explain crop effects.

As to field experimentation dealing specifically with the effects of one crop on another, Daubeny (*6*) in England was the first to undertake an extended study of the subject. Oats, barley, flax, tobacco, potatoes, beans, clover, and other crops were grown on small plots over a period of some ten years in continuous cultures and in rotation. As an average for all cropping combinations, rotation gave better yields than continuous culture for most crops, but in many instances this was not true of individual crop combinations. Daubeny's work has been cited in support of the plant-food theory, but Daubeny himself took a very conservative attitude in the matter, although he found little evidence of harmful root excretions.

Bedford and Pickering found that clover as well as grass may adversely affect the growth of fruit trees, whereas weeds do also but to less extent than grass. It was concluded that the toxic action does not accumulate in the soil and lasts only while the surface crop is growing. Some varieties of apples were affected more than others. In supplementary tests with specially devised pots, various crops were affected in varying degrees by the leachings from other growing plants. Hedrick (*11*) observed that on a rich soil

under irrigation in Utah catch crops of vegetables and small fruits exercised characteristic effects on color of foliage and growth of peach trees. In pot tests with a well-fertilized soil, cover crops of tomatoes, potatoes, oats, rye, rape, mustard, crimson clover, peas, and beans affected young peach trees somewhat differently. Oats and rye were most injurious, while beans and clover were beneficial. In a field test at Gizeh, Egypt, under arid conditions, Fletcher (7) grew corn and sesamum in alternating rows, different sections of the rows receiving different quantities of water and fertilizer. The corn greatly retarded the growth of the sesamum, and this effect was not overcome by the watering and fertilizing. Skinner (*19*) made the observation that cabbages did not grow well on a peat soil at Middle River, Calif., which had previously grown sesame.

The Howards (*12*) found that early turning under of a green-manure crop is essential for best results with tobacco, for sufficient time must be allowed for decay of the green manure before the tobacco is transplanted. It is stated that, for tobacco, green-manuring with *Crotolaria juncea* is successful only on light, high-lying, well-drained soils. On heavy or water-logged soils, green manure reduces the yield of tobacco. Stress is laid on the necessity of adequate soil aeration in tobacco culture. Hartwell and associates (*9*, *10*) conducted a field experiment in which 16 crops were grown on separate plots for two seasons, while a single crop was grown on all the plots in the third season. All plots were fertilized alike. After the various crops the yields of onions ranged from 13 to 412 bushels per acre; the yields of buckwheat ranged from 4 to 34 bushels; the yields of clover hay ranged from 2.5 to 4.3 tons. When the soil was limed to neutrality, the differences in the effects of the various crops on those which followed were much reduced. The effects of the preceding crops were not proportional to the quantities of plant nutrients removed from the soil. The soil acidity was affected differently by the several crops. According to Sewell (*18*) it is the general observation in the Great Plains area that wheat does not yield as well after Kafir as after *Zea mays* and in a field plot test extending over six years a gain of 3 bushels per acre was obtained with wheat after corn over the yield obtained after Kafir. The unfavorable effect of the Kafir is attributed to its toxic action on wheat.

Tobacco has been an important crop in certain sections for more than three centuries, and by farmers the crop has long been regarded as one which exhausts soils and some have considered it as especially injurious to the crop-producing power of the soil. Cocke (*5*, *p. 19*) in 1860 wrote: "Tobacco has been literally the besom of destruction, which has swept over this once fertile region [the tidewater region of Virginia], and reduced it to a state too poor to remunerate labor employed in its production." One reason for the development of this view is that a large portion of the tobacco crop has always been grown on light, sandy soils which naturally have a comparatively low crop-producing power. On the other hand, certain of these soils yield the best quality of tobacco, so that the tendency has been to grow tobacco year after year on the same soil. Under these circumstances, the system of farming rather than any peculiarity of the tobacco crop might account for the decline in general productiveness of these tobacco soils.

The early settlers learned that, in general, tobacco grew especially well on virgin soil, and it at once became the practice to constantly clear new land for tobacco. It was soon observed, however, that decline in tobacco yields under continuous culture of the crop is not always due to general exhaustion of the soil. Jones (*13*, *pp. 36–42*), writing in 1724, states: "When land is tired of tobacco it will bear Indian corn or English wheat, or any other European grain or seed, with wonderful increase." Some types of tobacco are grown on exceedingly rich soils, but, nevertheless, it is not possible to grow on such soils more than one or two satisfactory crops of tobacco in a period of some eight to ten years. In other cases exceedingly heavy applications of manures and fertilizers have failed to restore, for tobacco growing, the productiveness of soils on which the tobacco yield has declined under continuous culture. Finally, the yield of tobacco under continuous culture of the crop does not necessarily decline on all soils. In some sections tobacco has been grown each year on the same soil for more than a half century without decrease in yield.

## PURPOSE AND GENERAL PLAN OF THE EXPERIMENTS

As the area of cleared land in the older tobacco-growing sections constantly increased, the practice of resting

the "tobacco-tired" land for a period of years eventually came to largely supersede the custom of using virgin soil. It was found that from the standpoint of both yield and quality of product good results were obtained by growing occasional crops of tobacco and allowing the land to lie idle during the intervals. This system of cropping, which is really a rotation of tobacco and weeds or other adventitious vegetation, is especially applicable to sections where the acreage of cleared land greatly exceeds that needed for the tobacco crop and has been extensively followed in southern Maryland, where the present experiments have been conducted. A striking example of this practice is found in the culture of fine cigar-wrapper tobacco in the east coast district of Sumatra. There the land is cleared for a single crop of tobacco, followed perhaps by a dry crop of rice, after which the soil is left undisturbed for seven or eight years. During this period the original jungle growth is largely restored. Fertilizers may be used to advantage in this system of resting the land, but fertilizers alone apparently can not be employed as a substitute for fallowing.

There are two other important cropping systems in tobacco culture which involve more intensive methods. In Lancaster County, Pa., tobacco is grown in a rotation with wheat, grass, and red clover, and commonly a crop of corn immediately precedes tobacco in the rotation. The soils are strong naturally, and barn manure and some commercial fertilizer are applied to the tobacco crop. Under this system the tobacco yield is maintained at a rather high level (*8, p. 413*). This seems to be about the only successful rotation for tobacco which embodies Macaire's principle of substituting useful crops for weeds in the cropping system. The Connecticut Valley method consists essentially of continuous tobacco culture with very heavy annual applications of high-grade commercial fertilizers and liberal use of barn manure, with or without lime. On some soils this method has given very satisfactory results and large yields have been obtained. On other soils, however, the yield of tobacco rapidly declines. There are instances where one field on a farm continues to give excellent yields after continuous tobacco culture for more than a half century, while on another field the crop has become practically a failure after a few years, identical methods being applied on the two fields. In some cases root rot, due to *Thielavia basicola* (B. and Br.) Zopf, seems to satisfactorily account for the decline in yield, but in other instances diligent search for a causal parasite has thus far failed. It should also be recalled here that decline of the crop on old tobacco land, as already indicated, is by no means confined to the Connecticut Valley or to the cultural methods employed there.

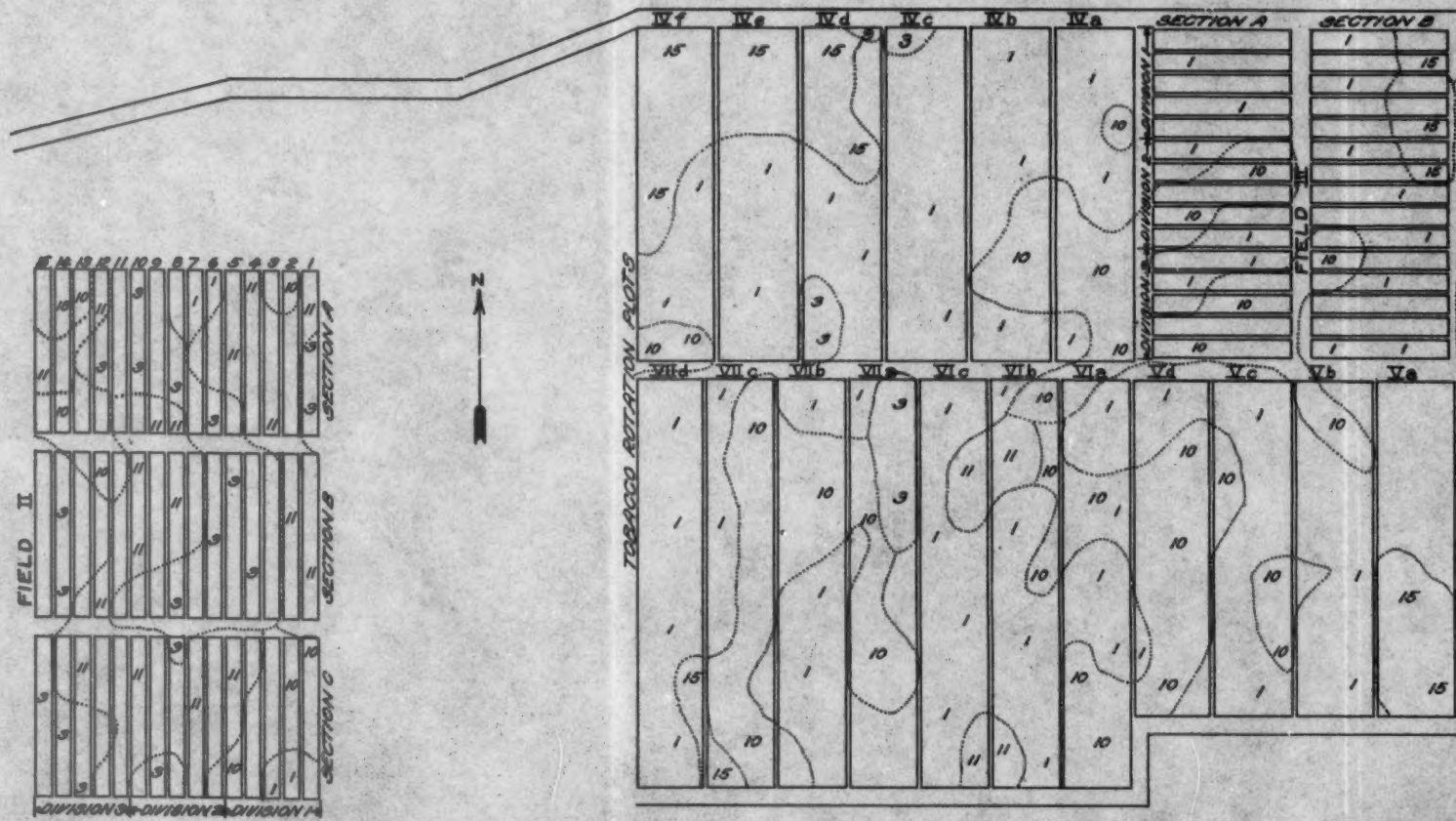
The field tests discussed here have consisted of two principal features and have been carried out primarily to furnish further information as to (1) why attempts to apply intensive methods in tobacco culture, either by using soil-improving crops or by heavy fertilizing and manuring, so commonly result in failure; and (2) whether tobacco is especially injurious to soil productivity as compared with such crops as corn and potatoes. The results of the tests seem to indicate that these two problems are rather closely interrelated.

The experimental tract is located immediately south of Upper Marlboro, in Prince Georges County, Md., and lies in the Atlantic Coastal Plain. The first series of tests, begun in 1912, include tobacco in continuous culture, with and without winter cover crops; in two-year rotations with wheat and legumes; in a three-year rotation with wheat and red clover; and on rested land. In two of the cropping tests no fertilizer has been applied, but in all cases the soil has been limed. These tests furnish data for a period of years as to the possibility of increasing the yield and improving the quality of tobacco by use of soil-improving crops, with and without addition of commercial fertilizers. The results have been rather surprising in several particulars.

The second series of tests, as originally planned and begun in 1914, had in view simply a direct comparison of the effects of tobacco, potatoes, and corn on soil productivity as measured by three succeeding crops, namely, wheat, oats, and rye. This experiment consisted essentially in growing the three hoed crops on adjoining parallel strips of land and then seeding the three small-grain crops crosswise these strips. Anticipating that the comparative effects of the hoed crops on the succeeding crops might be modified by fertilizers, the major cropping plots were subdivided uniformly into smaller plots which received different fertilizer treatments. The first results obtained were so surprising that it seemed desirable to extend the tests. As eventually developed, the scheme becomes substantially an effort to analyze through field experimentation the merits of a

## SOIL MAP TEST PLOTS UPPER MARLBORO, MD.

(Scale, 1 inch=100 feet)

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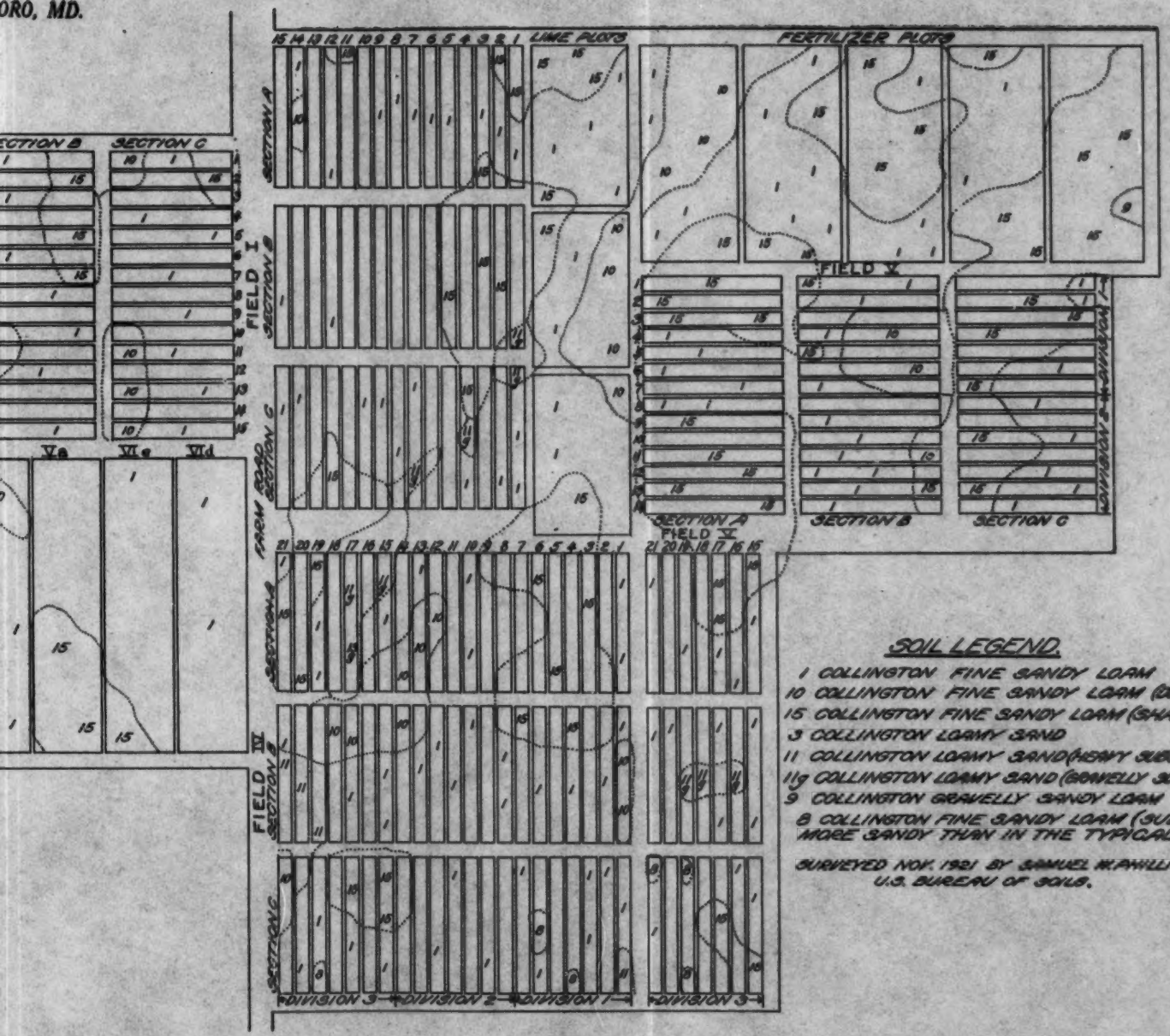
ORO, MD.




## SOIL LEGEND.

1 COLLINGTON FINE SANDY LOAM
10 COLLINGTON FINE SANDY LOAM (DEEP PHASE)
15 COLLINGTON FINE SANDY LOAM (SHALLOW PHASE)
3 COLLINGTON LOAMY SAND
11 COLLINGTON LOAMY SAND (HEAVY SUBSOIL BELOW 30")
11g COLLINGTON LOAMY SAND (GRAVELLY SUBSOIL PHASE)
9 COLLINGTON GRAVELLY SANDY LOAM
8 COLLINGTON FINE SANDY LOAM (SUBSOIL IS MORE SANDY THAN IN THE TYPICAL.)

SURVEYED NOV. 1921 BY SAMUEL W. PHILLIPS
U.S. BUREAU OF SOILS.

basic rotation of a hoed crop with a small-grain and a leguminous soiling crop, not as applied simply to a particular representative of each group to make up a single rotation, but applied under comparable conditions to each of three hoed crops, three small grains and four legumes, with addition of a grass mixture as a nonleguminous soiling crop. Thus each of the three hoed crops is grown in rotation with each of the three small grains and each of the five soiling crops, or in 15 complete rotations. The hoed crops also are grown in continuous culture and alternating among themselves, and in rotation with the small grains without use of soiling crops.

Viewed from a somewhat different angle, this plan embraces a systematic test of the effects of each crop on succeeding crops, except that the effects of the small grains *inter se* are not included. The basic rotation under study somewhat resembles that stated by De Candolle to have been in use in Norfolk, England, a century ago, consisting of a root crop, a winter cereal, and clover. In the tests in which soiling crops are not included, a comparison of four different fertilizer treatments has been made; while, with the soiling crops included, a calcium phosphate and sulphate of potash have been applied uniformly to all plots.

## PRELIMINARY STUDIES

### SOIL SURVEY OF THE EXPERIMENTAL PLOTS

The effects of crops on others that follow undoubtedly depend largely on soil conditions, and, moreover, for such a large number of plots as are here involved it is not to be expected that uniformity of soil can be had. It is desirable, therefore, to have as full information as practicable concerning the characteristics of the soils used in the tests. Accordingly, at our request, the Bureau of Soils made a survey[3] of all the plots, the results of which are shown in the soil map and the following report by S. W. Phillips:

The farm is located about one-fourth mile south of Upper Marlboro, Md., on a series of flat to undulating terracelike or bench areas rising above the Western Branch of the Patuxent River. The slopes between the higher and lower flats or benches are rather abrupt. The drainage is excellent, owing largely to the porous nature of the subsoil and the underlying substrata. The materials from which the soils have been derived are of marine origin. They contain considerable glauconitic[4] material or greensand "marl," and shells. In a bluff exposure along the north edge of the farm and in a road cut near the entrance to the fair grounds the greensand content is so high that the whole underlying strata has a greenish color. This material is of a sandy clay texture containing a few gravel and some small shells, which in places are cemented together into a loosely consolidated mass. During rains the greensand is washed out from the road cut, covering the roadbed with a green layer.

This region is known as the Atlantic Coastal Plain. The soil-forming materials of the region were transported by water from the older, higher country of the Piedmont and Appalachian regions to the north. They necessarily have undergone changes since washed from their original place of occurrence by processes of abrasion, solution, and decay. They are high in content of quartz particles and, as above stated, contain glauconite, a mineral not generally present in the soil of the great Coastal Plain region.

The soils of the experiment plots have been included in the Collington series, which typically has a brown or yellowish-brown surface with a yellowish-brown, yellow, or greenish-yellow subsoil. The lower subsoil is usually more friable and contains a higher percentage of coarse-grained sand than the upper portion of the subsoil. The amount of the greensand material varies considerably. In places there is so little that the soil would have been mapped as the Sassafras if such areas had been of sufficient size and importance. There is, nevertheless, some greensand in all of the soil. The range of content is from a percentage so low as scarcely to impart a greenish cast to a percentage high enough to give a very decided greenish color. The deep-green material of the exposures referred to represents the parent material, that is, the material from which the overlying soils have been formed through weathering and decay of the greensand beds. There is in these soils, of course, much material not derived from greensand, but rather from the quartzal and other particles associated with the greensand bed. On the slopes outcroppings of gravel are sometimes present.

Three soil types and five type phases[5] are present on the farm. The texture of the soil and subsoil, that is, the relative content of gravel, sands, silt, and clay, defines the soil-type variations in the depth of the surface layers of sand or sandy loam, and slight variations in the character of the subsoil are the factors which here have governed subdivision of portions of the types into subclasses or phases.

*The Collington fine sandy loam (No. 1).*—This is the most extensive soil on the farm. It is a brown fine sandy loam to loamy fine sand in the surface portion, this passing at about 7 to 10 inches into the subsurface layer of yellowish-brown or brownish-yellow fine sandy loam or loamy fine sand. The subsoil, beginning at about 16 to 22 inches, consists of yellowish-brown to a reddish-yellow sandy clay or silty clay loam. In places the greensand content is so high that the subsoil has a greenish-brown or dark green color. The greensand is present typically principally in the subsoil, but there may be small amounts in the surface soil as well. Below a depth of about 30 inches the content of coarse-grained material is higher and the subsoil accordingly is more porous and open. On the lower bench, near the tobacco barn, the surface runs higher than the average in content of medium sand, approaching here the texture of a sandy loam. The surface soil of Fields I, III, and V of the highest bench contains a little more fine sand and silt than the average of the Collington fine sandy loam. A few patches here of unimportant size are as heavy as a very fine sandy loam. The content of greensand is higher in the nitrogen and potash plots of the lower bench than in the fields of the higher level. This may be due or partly due to a transportation by rain water of greensand from the outcropping deposit on the slope of the lower level. In parts of Plots IVb, IVc, and IVd the amount of greensand

[3] Survey made by Samuel W. Phillips, under direction of Hugh H. Bennett, inspector, southern division, Soil Survey Investigations, Curtis F. Marbut, in charge, Bureau of Soils.

[4] Glauconite is a hydrous silicate of potassium and iron.

[5] A phase is a minor soil variation of local importance.

is very low, such areas really representing a low-greensand-content phase of the Collington fine sandy loam.

*Collington fine sandy loam, shallow phase (No. 15).*—In this phase the surface layer of fine sandy loam or loamy fine sand is not so deep as in the typical soil, ranging from 4 to 12 inches in thickness. This soil comprises a few very small patches at the north ends of Plots IVe and IVf and Plots 1 and 2 of Field I and the north end of the lime plots where the underlying sandy clay or silty clay loam is exposed at the surface in some places. None of this phase is found on the lower benches. It is most important in the eastern half of the upper bench.

*Collington fine sandy loam, deep phase (No. 10).*—This phase includes areas of Collington fine sandy loam in which the surface and subsurface layers extend to a depth of about 22 to 30 inches before the sandy clay subsoil is reached. The soil is a brown fine sandy loam or loamy fine sand, while the subsurface layer is a yellow to yellowish-brown sandy loam to loamy fine sand, rather loose in some places. Most of the special potash plots and parts of the special potash and magnesium plots of the lower bench, as well as fairly large area of all of the fields on the upper bench of the eastern part of the farm, consist of this soil.

*Collington fine sandy loam, sandy subsoil phase (No. 8).*—In this phase the surface layer is a brown fine sandy loam or heavy fine sandy loam, while the subsurface consists of yellow or yellowish-brown, somewhat compact fine sandy loam. At a depth of about 18 to 24 inches there is a coarser-textured, more open brown sandy loam or yellow loamy sand, which continues with but little or no change to depths of 36 inches or more. This phase is of small total extent, and is restricted in occurrence to the southern part of Field IV.

*Collington loamy sand (No. 3).*—This soil is a brown medium sand containing some coarse sand and fine gravel. At about 8 to 10 inches yellowish-brown or yellow loamy sand, with considerable greensand material, comes in and continues to depths of 3 feet or more. Some gravel is present, particularly near areas of gravelly sandy loam, and on these slopes where there are gravel outcrops. This type occupies much of the supplementary special nitrogen and the special potash plots; it also occurs in the southwestern corner of the special nitrogen plots on the lower bench and covers about one-third of Field II on the second level. On the higher level it is found only in the tobacco rotation plots.

*Collington fine sandy loam, heavy subsoil phase (No. 11).*—This phase includes variations in which the lower subsoil at depths of about 32 to 36 inches consists of a yellowish to yellowish-brown sandy clay. In places some small gravel is found, and greensand is present in the subsoil and in lesser amount in the soil. It occurs chiefly in the supplementary special nitrogen and special potash plots, in Field II and in the tobacco rotation plots.

*Collington fine sandy loam, gravely subsoil phase (No. 11g).*—This phase differs from the typical Collington fine sandy loam in having a subsoil of sandy clay containing a considerable amount of gravel at depths below about 24 inches. Areas of this phase occur in the supplementary special nitrogen plots, in the special potash and magnesium plots on the lower level, and in Fields I, IV, and V, and the lime plots in the higher level.

*Collington gravelly sandy loam (No. 9).*—This type is a light-brown gravelly sandy loam, which passes into light yellowish-brown sandy loam at depths of about 8 to 10 inches, this, in turn, passing into yellowish-brown friable sandy clay at about 24 inches. The subsoil is gravelly, in places being difficult to bore into with the soil auger. The subsoil contains varying amounts of greensand, the lower part containing the higher percentage. This type is found in the special nitrogen and supplementary special nitrogen and special potash plots, in plot IVd of the tobacco rotation plots, and in sections B and C of Field IV.

TABLE I.—*Chemical analysis [a] of greensand and Collington sandy loam*

| | Greensand at Marlboro | Soil [b] 0 to 7 inches | Subsoil [b] 7 to 36 inches | Soil [b] | Subsoil [b] 9 to 36 inches | Subsoil [c] 8 to 36 inches |
|---|---|---|---|---|---|---|
| | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* |
| Potash ($K_2O$) | 2.565 | 0.888 | 0.445 | 0.910 | 0.376 | 0.858 |
| Soda ($Na_2O$) | .391 | .718 | 2.401 | .418 | .692 | .980 |
| Lime (CaO) | .170 | .155 | .110 | .155 | .210 | .140 |
| Magnesia (MgO) | .740 | .396 | .474 | .185 | .336 | .136 |
| Manganese oxide (MnO) | | .030 | | .035 | .037 | .037 |
| Iron ($Fe_2O_3$) | 16.306 | 4.011 | 9.067 | 3.632 | 6.248 | 9.488 |
| Alumina ($Al_2O_3$) | .130 | 2.448 | 4.097 | 2.856 | 4.742 | 4.011 |
| Phosphoric acid ($P_2O_5$) | .065 | .054 | .104 | .053 | .076 | .088 |
| Sulphuric acid ($SO_3$) | .012 | .116 | .096 | .110 | .056 | .132 |
| Insoluble | 74.049 | | | | | |
| Moisture | 2.130 | | | | | |
| Volatile organic matter | 1.975 | | | | | |

[a] From Soil Survey of Prince Georges County, Md. U. S. Bureau of Soils.
[b] Sample from Mullikin, Md.
[c] Sample from Oak Grove, Md.

TABLE II.—*Monthly record of rainfall, in inches, on experimental fields for April, May, June, July, August, and September, 1912–1923*

| Month | 1912 | 1913 [a] | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | 0.62 | 6.18 | [a] 4.04 | [a] 1.33 | 1.63 | 3.45 | 6.05 | 3.91 | 4.81 | 2.78 | 1.10 | 3.23 |
| May | 1.31 | 6.07 | [a] 1.67 | 2.33 | 5.82 | 2.22 | 2.00 | 6.66 | 1.06 | 5.07 | 4.60 | 1.78 |
| June | 4.74 | 1.81 | 2.68 | 2.40 | 6.03 | 3.00 | 2.27 | 2.29 | 5.72 | .77 | 8.26 | 2.99 |
| July | 5.18 | 1.54 | 2.69 | 3.05 | 3.39 | 3.18 | 2.11 | 6.64 | 2.83 | 3.14 | 6.74 | 3.72 |
| August | .68 | 3.89 | 2.80 | 7.40 | 2.97 | 1.46 | 5.66 | 4.30 | 4.30 | 2.88 | 3.82 | 2.86 |
| September | 6.13 | 3.35 | .16 | .45 | 2.02 | 1.77 | 1.99 | 1.69 | 3.32 | 1.82 | .63 | 2.53 |
| Total | 18.66 | 22.84 | 14.04 | 16.96 | 21.86 | 15.08 | 20.08 | 25.49 | 22.04 | 16.46 | 25.15 | 17.11 |

[a] Data for 1913 and for April and May, 1914, and April, 1915, are those of the Weather Bureau for Cheltenham, Md., about 5 miles distant.

### RAINFALL

It is of considerable interest to inquire as to what extent weather conditions, especially rainfall, may modify the effects of a crop on succeeding crops. The available records of rainfall on the experimental fields during the spring and summer months for the period of the experiments are given in Table II.

## SPECIAL CROPPING TESTS WITH TOBACCO

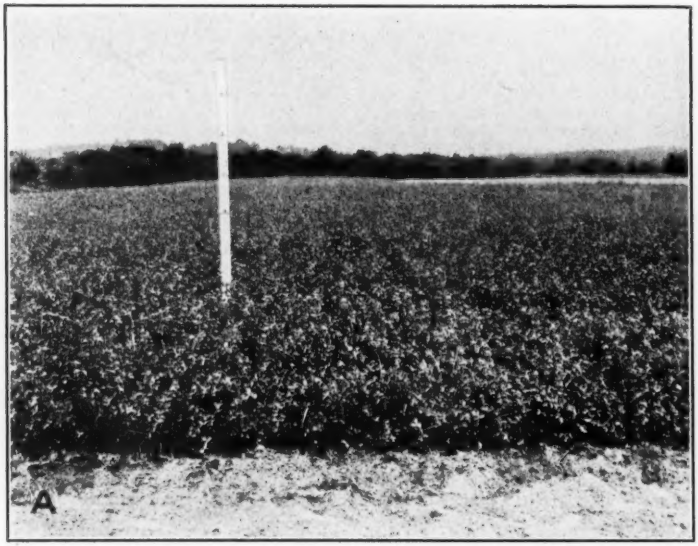
The plots used in these tests are one-fourth acre in size. The numbers of plots and treatments for each cropping test are as follows:

IV *a*, *b*, *c*: Tobacco, wheat, and red clover in a three-year rotation; tobacco fertilized.
V *a*, *b*: Tobacco, wheat, and crimson clover in a two-year rotation; tobacco fertilized.
VI *a*: Tobacco each year, crimson clover as a cover crop; no fertilizer used.
VI *b*: Tobacco each year, crimson clover as a cover crop; tobacco fertilized.
VI *c*: Tobacco each year, hairy vetch as a cover crop; tobacco fertilized.
VI *d*: Tobacco each year, rye as a cover crop; tobacco fertilized
VI *e*: Tobacco each year, no cover crop; tobacco fertilized.
VII *a*, *b*: Tobacco, wheat, and cowpeas in a two-year rotation; tobacco fertilized.
VII *c*, *d*: Tobacco, wheat, and cowpeas, in a two-year rotation; no fertilizer used.

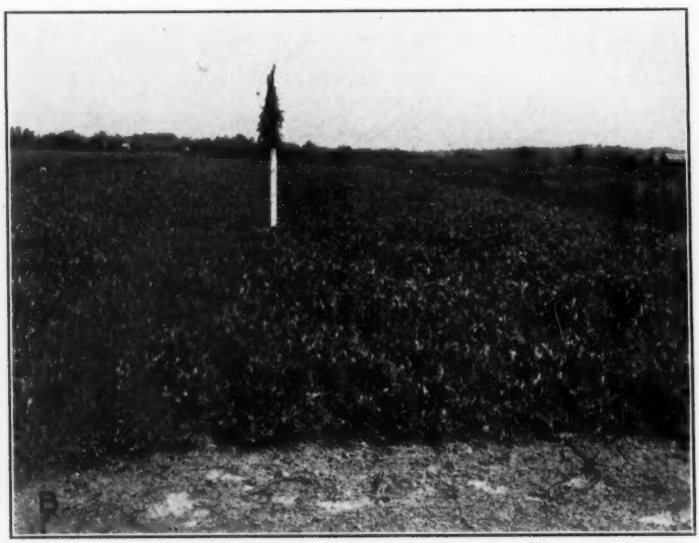
The location and arrangement of these plots and the general character of the soil are shown in the soil map, the plots being numbered there as above. (Some of the plots included in the survey relate to experiments not involved in the present discussion.) All of the tests were begun in 1912, except those on Plots VI *d* and VI *e*, which were begun in 1916, a period of four years having been allowed to fully establish the legume features of the tests. In Series IV, V, and VII, tobacco was grown on Plot *a* in 1912, Plot *b* in 1913, and so on, in regular sequence. In 1922 plots were added immediately south of Series V *a*, *b* for the purpose of growing tobacco every second and third year, respectively, in rotation with weeds. Fertilizer has been applied each year to the tobacco crop, but none has been used on the wheat or soil-improving crops. For the years 1912 to 1915, inclusive, the fertilizer consisted of 100 pounds nitrate of soda, 500 pounds 14 per cent acid phosphate and 100 pounds 50 per cent sulphate of potash per acre. Beginning with 1916 the application of nitrate of soda was reduced to 60 pounds per acre but no change was made in the quantities of acid phosphate and sulphate of potash used. In the years 1912, 1913, and 1914 air-slaked burned lime was applied at the rate of 10 bushels per acre to the plots in each series at the time of turning under the legumes in preparation for tobacco. No lime was used in 1915. Beginning with 1916 ground limestone has been applied in all cases after tobacco, prior to seeding wheat. Each plot in Series IV and VI has received 1,000 pounds per acre once in each three-year period, and the plots in Series V and VII have received 650 pounds once in each two-year period. All legumes have been plowed under, except that one crop of hay has been cut each year from the first-year red clover.

In general, excellent stands and good growth of red clover have been obtained with but little winter killing (pl. 1, A). Crimson clover grown in the two-year rotation with tobacco and wheat has usually made excellent growth when it has escaped winter killing. Rather frequently, however, it has suffered severely from cold, and, altogether, has not been a dependable soil-improving crop. In recent years the crimson clover has been damaged considerably by stem-rot disease. With continuous tobacco culture, with fertilizer, crimson clover has been somewhat less successful than in the two-year rotation for the reason that the tobacco crop comes off too late to allow seeding of the clover at the proper time. Where no fertilizer is applied to the tobacco, crimson clover has been almost a complete failure. Hairy vetch has proved to be a thoroughly dependable winter cover crop, and there has been no winter killing of consequence in spite of the fact that it has been necessary to seed it very late in the fall (pl. 1, B). The vetch has furnished large quantities of organic matter for the soil. The cowpeas have always made good growth where fertilizer was applied to the tobacco (pl. 2, A), but the growth has been much less where no fertilizer was used. Data have been obtained on the yields of wheat in these tests but will not be considered in this discussion.

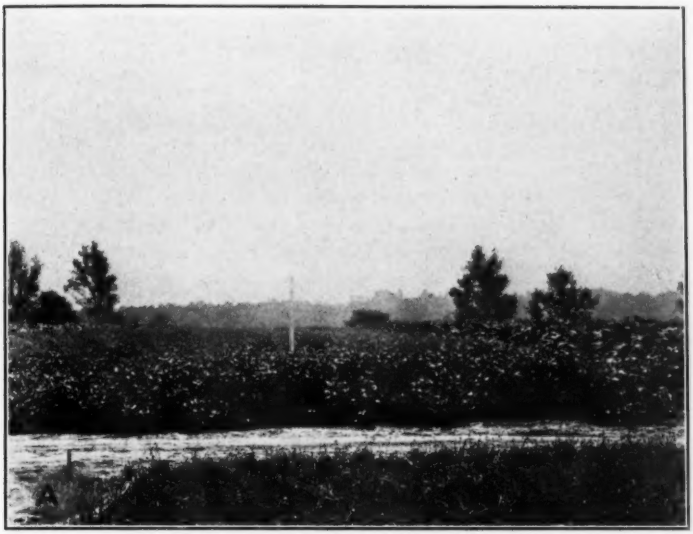
The yields and gross value of tobacco produced under the several systems of cropping are summarized in Table III. The values of the crops from the different plots are based on the judgment of local tobacco buyers.




A.—Excellent stand and good growth of red clover in a 3-year rotation of tobacco, wheat, and red clover. In comparison with other soiling crops, red clover has given best results with tobacco, but it is possible that this is not due so much to the specifically favorable effect of the clover as to the fact that the cropping system virtually involves resting the land for two years prior to transplanting the tobacco crop. (Compare pl. 4, B)




B.—Growth of hairy vetch as a catch crop in continuous tobacco culture. Hairy vetch as a winter cover crop has made excellent growth each year with almost no winter killing. In the early years of the test, vetch, as a soiling crop, gave large yields of tobacco of good quality, but subsequently the yield has been very variable, with a tendency to decline, especially in wet years



A.—Growth of cowpeas in a two-year rotation of tobacco, wheat, and cowpeas. The growth of cowpeas has been large and the crop has added large quantities of nitrogen to the soil. This legume has given somewhat better results with tobacco than have most other legumes tested. None of the legumes, however, has given anything like as large average increases in yield of tobacco as would be expected on the basis of the nitrogen added to the soil

B.—Tobacco in rotation with rye and soiling crops on Field IV. Plot in center shows the slow and very uneven growth after soy beans. Plot to right shows the marked depressing effect of grass as a cover crop. Note the much larger and more uniform growth of tobacco following cowpeas in plot at extreme left

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TABLE III.—*Yields and gross values of tobacco in special cropping tests, 1912–1923*

YIELDS OF TOBACCO LEAF, POUNDS PER ACRE

| Plot series and cropping system | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | Average 1912–1923 | Average 1916–1923 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IV. Tobacco, wheat, red clover | 584 | 884 | 1,284 | 1,080 | 1,200 | 1,060 | 1,176 | 1,264 | 1,354 | 1,312 | 741 | 1,217 | 1,096 | 1,166 |
| V. Tobacco, wheat, crimson clover | 416 | 1,116 | 1,212 | 972 | 1,356 | 1,108 | 768 | 1,266 | 672 | 1,022 | 437 | 1,280 | 969 | 989 |
| VI. *a*. Tobacco, crimson clover, no fertilizer | 570 | 978 | 1,404 | 696 | 676 | 640 | 752 | 342 | 380 | 464 | 105 | 425 | 619 | 473 |
| VI. *b*. Tobacco, crimson clover, with fertilizer | 952 | 1,108 | 1,568 | 924 | 1,384 | 1,114 | 882 | 833 | 748 | 912 | 273 | 960 | 974 | 892 |
| VI. *c*. Tobacco, vetch | 916 | 1,296 | 1,692 | 908 | 1,283 | 1,604 | 1,191 | 730 | 812 | 1,152 | 590 | 1,560 | 1,145 | 1,115 |
| VI. *d*. Tobacco, rye | ----- | ----- | ----- | ----- | 948 | 834 | 1,058 | 667 | 534 | 684 | 467 | 876 | ----- | 759 |
| VI. *e*. Tobacco, fallow | ----- | ----- | ----- | ----- | 824 | 896 | 938 | 1,013 | 1,002 | 984 | 655 | 904 | ----- | 902 |
| VII. *a, b*. Tobacco, wheat, cowpeas, with fertilizer | 816 | 1,304 | 1,664 | 920 | 1,456 | 1,268 | 1,124 | 970 | 1,288 | 974 | 672 | 1,332 | 1,149 | 1,136 |
| VII. *c, d* Tobacco, wheat, cowpeas, no fertilizer | 744 | 896 | 1,348 | 756 | 840 | 709 | 960 | 268 | 764 | 604 | 377 | 738 | 750 | 658 |

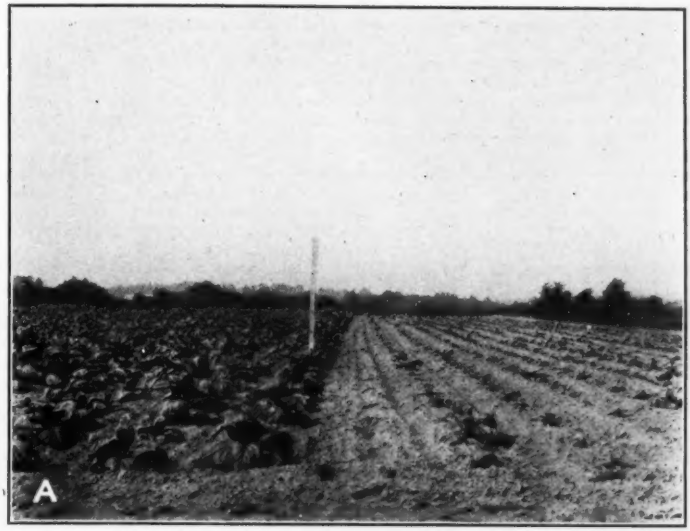
GROSS VALUES OF TOBACCO, DOLLARS PER ACRE

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IV. Tobacco, wheat, red clover | 58 | 68 | 131 | 163 | 242 | 214 | 378 | 597 | 444 | 374 | 172 | 339 | 265 | 345 |
| V. Tobacco, wheat crimson clover | 42 | 94 | 109 | 161 | 274 | 323 | 229 | 583 | 186 | 234 | 48 | 339 | 219 | 277 |
| VI. *a*. Tobacco, crimson, clover, no fertilizer | 50 | 74 | 131 | 79 | 107 | 120 | 159 | 52 | 30 | 37 | 3 | 18 | 72 | 66 |
| VI. *b*. Tobacco, crimson, clover, with fertilizer | 97 | 94 | 190 | 108 | 273 | 323 | 260 | 334 | 182 | 186 | 27 | 261 | 195 | 231 |
| VI. *c*. Tobacco, vetch | 94 | 108 | 198 | 144 | 285 | 430 | 392 | 301 | 254 | 248 | 85 | 371 | 243 | 296 |
| VI. *d*. Tobacco, rye | ----- | ----- | ----- | ----- | 178 | 187 | 316 | 287 | 129 | 99 | 68 | 311 | ----- | 197 |
| VI. Tobacco, fallow | ----- | ----- | ----- | ----- | 155 | 204 | 266 | 425 | 272 | 312 | 170 | 330 | ----- | 267 |
| VII. *a, b*. Tobacco, wheat, cowpeas, with fertilizer | 94 | 107 | 203 | 151 | 300 | 340 | 351 | 140 | 266 | 217 | 98 | 423 | 224 | 267 |
| VII. *c, d*. Tobacco, wheat, cowpeas, no fertilizer | 64 | 66 | 132 | 83 | 141 | 162 | 263 | 28 | 53 | 62 | 33 | 153 | 103 | 112 |

## DISCUSSION OF RESULTS

In analyzing the results of the tests it will be profitable to consider the averages for the period covered, the yearly variations, and the general trend under the several treatments, the latter being more readily presented in graphic form. For the whole period of the tests, 1912 to 1923, inclusive, where fertilizer was used, an average yield of about 1,150 pounds of tobacco per acre has been obtained in continuous culture with vetch as a cover crop and in a two-year rotation of tobacco and wheat with cowpeas as a soiling crop. For the same period a yield of about 1,100 pounds of tobacco leaf has been obtained in the three-year rotation of tobacco, wheat, and red clover. The last-named rotation has given the best quality of cured leaf. A yield of somewhat less than 1,000 pounds has been obtained both in continuous tobacco culture with crimson clover as a cover crop and in a two-year rotation of tobacco and wheat with crimson clover as a soiling crop. The latter, however, has given a somewhat better quality of leaf. In continuous culture with crimson clover as a cover crop, and in the two-year rotation with crimson clover and cowpeas as a soil-improving crop, omission of the fertilizer has greatly reduced the yield and value of the tobacco (pl. 3, A). Under these conditions the tobacco after cowpeas and the cowpeas themselves have shown well-defined symptoms of potash hunger, and leaf spot resembling wildfire and black fire of tobacco has been decidedly more prevalent than where fertilizer has been applied.

For the period 1916 to 1923, inclusive, continuous culture of tobacco with fertilizer, but without use of any cover crop, has given a yield of 900 pounds per acre and the product has been of good quality. With rye used as a cover crop there was an unexpected lowering of the average yield of tobacco and the value of the crop was lowered to an even greater degree. The use of crismon clover and cowpeas as soiling crops, without addition of commercial fertilizer, has greatly reduced the yield and value of the tobacco as compared with a tobacco crop every year with fertilizer but without soiling crop. The three-year rotation of tobacco, wheat, and red clover has given best yields and best quality of




A.—Continuous tobacco culture, with crimson clover as a winter cover crop. On plot at right no fertilizer is applied, while tobacco on plot at left is fertilized every year. The plots have been limed uniformly

B.—Tobacco on rested land, 1923. The soil has not been under cultivation for more than 10 years. Photographed August 6. Note the more advanced and uniform growth as compared with the tobacco of the same age shown in A

tobacco. Cowpeas in the two-year rotation give an increase of something more than 200 pounds over continuous tobacco culture without cover crop but there is no increase in value of the product. Vetch as a cover crop gives about the same gain in yield as the cowpeas in the two-year rotation and also gives some increase in value of the tobacco. Of the several legumes, crimson clover continues to give the lowest yields, while as a cover crop in continuous tobacco culture it has been less effective in maintaining yields than in the two-year rotation which includes wheat. Comparing the period 1916 to 1923, inclusive, with the period on all plots. These relationships are more clearly shown in Figures 1, 2, and 3. In some years vetch as a cover crop has given very large increases in yield while in other years the yield has been actually depressed. Evidently the effect of the vetch is dependent largely on weather conditions. By comparing the yields of tobacco from year to year with the rainfall during the summer months (Table II), it will be found that the large increases in yield of tobacco usually occur in relatively dry seasons and the poor yields usually in wet seasons.

This relationship between the effect of the cover crop and the rainfall, which

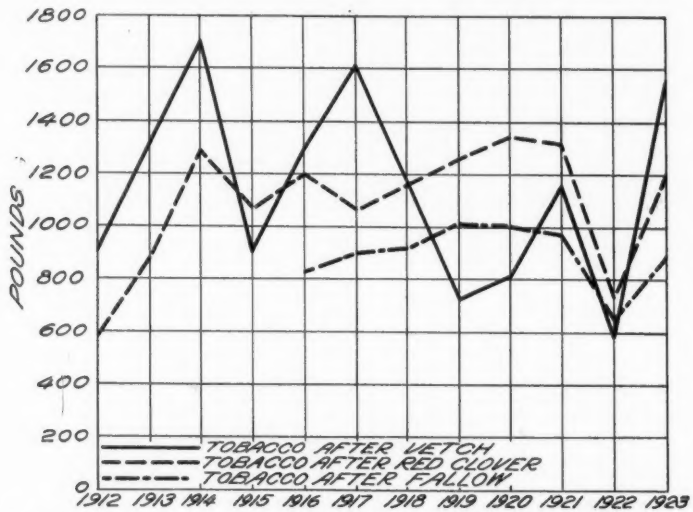



FIG. 1.—Annual yields of tobacco, 1912–1923, inclusive: (1) in continuous culture, with hairy vetch as a cover crop; (2) in a 3-year rotation of tobacco, wheat, and red clover; (3) in continuous culture, with no cover crop. Note the extremely wide fluctuation in yield from year to year and the downward trend in yield after vetch, in contrast with the relatively stabilized yield after clover and with no cover crop and the upward trend in yield after the red clover

1912 to 1923, inclusive, it will be observed that the three-year rotation which includes red clover is the only cropping system showing a gain in yield of tobacco, all others showing no change or a decline.

An outstanding feature of the results with vetch as a cover crop is the extremely wide range in yield of tobacco from year to year. Similar, though somewhat smaller, fluctuations in yield are obtained from other legumes in the rotation and from rye as a cover crop. By way of contrast, the yields in the red-clover rotation and on the fallow plot are relatively constant, except in 1922, when poor yields were obtained seems to hold also for other cover crops, is important. It has often been suggested that turning under large quantities of green manures may cut off the normal upward capillary movement of moisture in the soil. This factor could hardly be of significance in the present case, since the unfavorable action of the vetch occurs in seasons of abundant rainfall. Again, cowpeas in the rotation have much the same effect as vetch, and since the cowpeas are grown in the precedng year they would certainly decay sufficiently before the tobacco crop is transplanted to obviate interference with movement of soil moisture. It is plain,

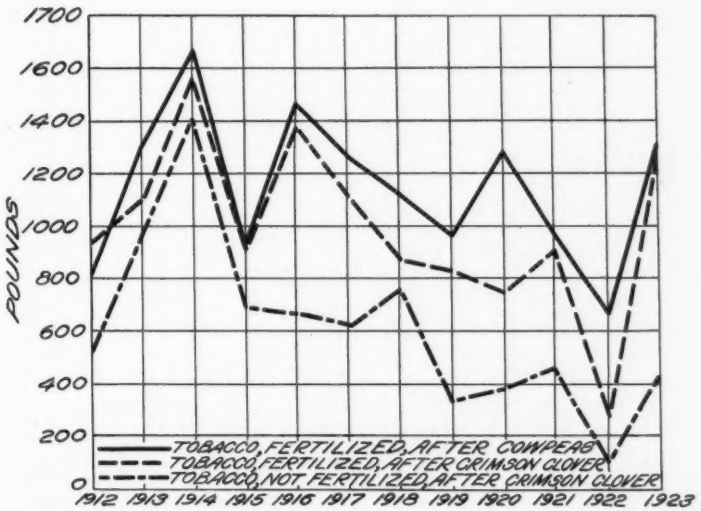



FIG. 2.—Annual yields of tobacco, 1912–1923, inclusive: (1) In a two-year rotation of tobacco, wheat, and cowpeas (turned under), tobacco crop fertilized; (2) in continuous culture, with crimson clover as a cover crop, tobacco fertilized; (3) in continuous culture, with crimson clover as a cover crop, tobacco not fertilized. In all cases the general trend in yield is downward, the initial gains from legumes not being maintained. Omission of fertilizer for tobacco, even when legumes are grown, soon leads to practical crop failure

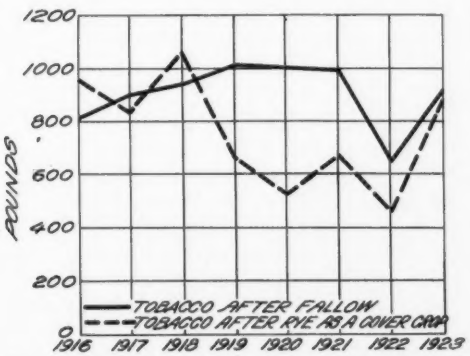


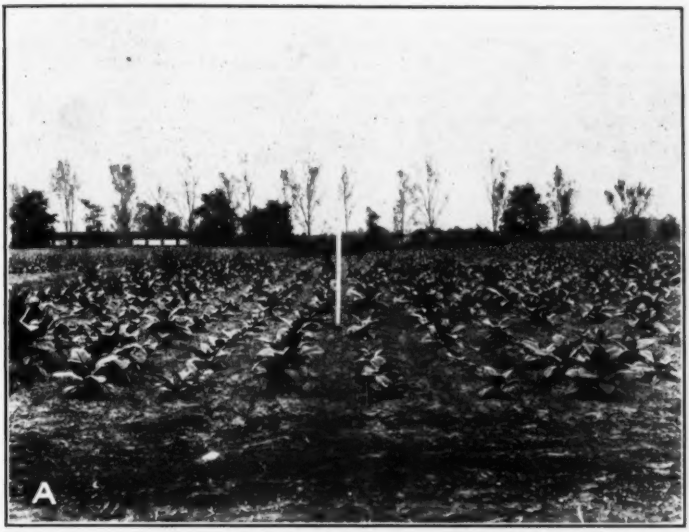

FIG. 3.—Annual yields of tobacco in continuous culture, 1916–1923, inclusive, without use of a cover crop and with rye as a cover crop. At the beginning and in certain subsequent years, the yields after rye were about the same as without cover crop. In relatively wet seasons, however, the yield is markedly depressed by the rye cover crop

also, that the depressing effect of rye on the yield of tobacco is dependent largely on seasonal conditions. With tobacco, an inadequate supply of nitrogen is usually recognizable by the light-green or yellowish-green color of the leaf. After both rye and the leguminous cover crops, the tobacco frequently shows an abnormally dark-green color. A sample of green leaves taken in 1923 from tobacco plants on the vetch plot which had made poor growth showed a nitrogen content of 4.98 per cent in the leaf as against 3.84 per cent in the leaves from large plants on the same plot. Evidently there was no shortage of nitrogen, for usually the nitrogen content of Maryland tobacco does not exceed 2.5 per cent. On the other hand, it is obvious that there could be no excess of nitrogen on the rye plot. The excellent crops of red clover which have been obtained show that the rate of liming has been adequate for ordinary requirements, while anything like excessive liming has been carefully avoided.

The data presented graphically in Figures 1, 2, and 3 indicate for the period of the tests a downward trend in yields from use of rye, crimson clover, vetch, and cowpeas, as soil-improving crops. While the time covered is rather short, it seems unlikely that there will be any permanent return to the relatively high level of yields of the early years. During this same period there has been an upward trend in yields in the 3-year rotations with wheat and red clover, and thus far there has been no significant change in the results where no soiling crop is employed. Whether red clover, as against the other soiling crops used, has some specifically favorable effect on the tobacco crop or the improvement in growth of tobacco is due to virtual resting of the land for two years will require further study. The downward trend in yield where legumes are used but fertilizer omitted has been very marked. In 1922 a series of plots were located immediately south of the older series which provide for 2 and 3 year rotations of tobacco and weeds. The land had not been cropped for many years, and the results with tobacco for 1922 and 1923 really represent tobacco crops on land which had been rested for more than 10 years. The average yields per acre from duplicate plots were 880 pounds in 1922, and 1,332 pounds in 1923, and the corresponding crop values were $251 and $524. In the wet year of 1922 the yield on the rested land was not equaled by that on any of the older cropping plots, and in the generally favorable year of 1923 the yield was exceeded only by that on the vetch plot. In both years the quality of the tobacco on the rested land was decidedly superior to that on any of the older plots.

The reduced yield and value of the tobacco crop which so often occur where soiling crops are used are due primarily to the very uneven growth of the tobacco plants, as shown in Plate 4, A. It frequently happens that many of the stunted plants, after a long delay, make approximately normal growth very late in the season, but under these conditions the quality of the product is almost invariably poor. The even growth on fallow or rested land is shown in Plate 4, B. It is difficult to definitely eliminate parasitism as a possible factor in these results, but it is apparent that any causal parasite must be capable of attacking a wide range of plants, while, on the other hand, it would be necessary to assume a decided selective action as between, for example, red clover and crimson clover. It is to be kept in mind, also, that the soil-improving crops themselves have shown no evidence of injury from disease or decrease in growth during the progress of the tests, except that crimson clover has been injured by the stem-rot disease. Associated with reduced growth of the tobacco, there is reduction in root development and the root system as a whole has a yellowish or brownish color. It is interesting to note that at times the tobacco plants on the rye plot wilt during the middle of the day, whereas there is no indication of wilting on the fallow plot immediately adjoining. Little or no Thielavia root-rot has been found on any of the plots.

From a practical standpoint it seems clear that application of intensive methods which include use of soil-improving crops is not likely to prove altogether successful in tobacco culture, at least under the conditions of these tests. Where land values or other factors increase the necessity for intensive methods, apparently the most promising cropping system is a rotation of at least three years, which includes wheat and red clover. It is hardly to be expected, however, that the results obtained in the present tests will hold true on all tobacco soils; and, in fact, the crop effects here in question seem to be peculiarly dependent both on weather and on soil conditions. It seems fair to assume, moreover, that under proper conditions occasional and cautious use of legumes may give good




A.—Tobacco in continuous culture, with rye as a cover crop. Note the uneven and greatly reduced growth as compared with the crop on adjoining plot. (See B)

B.—Tobacco in continuous culture, without cover crop. Note the uniform growth over the plot as a whole. This plot adjoins that shown in A

results even on the soils used in the present tests. But no system of active cropping seems to give such uniformly good results as resting the land, thus allowing it to be occupied for a time by adventitious vegetation (pl. 3, B).

## FIELD STUDY OF THE COMPARATIVE EFFECTS OF TOBACCO AND OTHER CROPS ON THE YIELDS OF SUCCEEDING CROPS

In these tests tobacco has been compared, in all instances, with early potatoes and corn. Each of these crops has been grown (1) in continuous culture and in alternation with each of the other two; (2) in rotation with each of the small grains, wheat, oats, and rye; and (3) in rotation with each of the small grains and each of two winter legumes, two summer legumes, and a grass mixture. Except where the soiling crops are used, four different fertilizer treatments have been applied in each system of cropping. To carry out these tests has required 5 separate fields and a total of 261 plots. The second feature of the tests was begun in 1914, but the entire plan was not in full operation till 1916. The results to be presented at this time are more or less of a preliminary nature and are subject to some modification as the work progresses. For this reason only summarized tabulations of yields will be given, leaving for future publication a more complete presentation of the detailed results for each year.

The general plan in conducting the tests has been to plant the three hoed crops—tobacco, potatoes, and corn—in adjoining, parallel strips of suitable size, the total area embraced in the three strips being designated as a "field." The three strips embraced in a field are called "sections," designated by the letters A, B, and C. In the second year three crops, consisting of the same three hoed crops or three small grains, as the case may be, are planted crosswise the original strips or sections and the strips occupied by the second-year crops, which run at right angles to the sections, are called "divisions." These divisions are distinguished by the numbers 1, 2, and 3. This of course provides for each of the first-year crops to be followed by each of the second-year crops. Thus, each of the three sections of the field occupied by a first-year crop is crossed by each of the divisions occupied by a second-year crop, and vice versa. The effect is to divide the field into nine "cropping units,' each of which embraces a complete 2-year rotation of a first-year and a second-year crop. The location of these cropping units on the field, as well as the cropping system applied to them, are readily identified by combining the section and division designations, as, for example, C 1, A 2.

### FERTILIZER TREATMENTS

By making the cropping units of sufficient size they may be subdivided into as many plots as desired for fertilizer tests or for adding legumes to the rotations, both of which features have been made a part of these tests. In this way it becomes possible to compare crop effects with fertilizer effects and, moreover, the plan may be made to furnish a comprehensive test of the fertilizer needs of the soil. In the present tests only four different fertilizer treatments have been used, involving omission of nitrogen, phosphoric acid, and potash, respectively, in comparison with a standard rate of application of the three elements. High-grade dried blood has been used as a source of nitrogen because it supplies only small percentages of phosphorus, potassium, magnesium, sulphur, or other plant-food elements. A chemically precipitated dicalcic phosphate has furnished phosphoric acid, and high-grade sulphate of potash has been used as a source of potash. The standard rates of application per acre, arbitrarily selected, were 20 pounds each of nitrogen and potash and 40 pounds of available phosphoric acid. For convenience in indicating the different fertilizer treatments, the letters N, P, and K are used to designate applications of 20 pounds nitrogen, 40 pounds phosphoric acid, and 20 pounds potash per acre, respectively. The standard rates of application per acre with the corresponding symbols, therefore, are as follows:

| | | |
|---|---|---|
| 1. | 20 pounds nitrogen<br>40 pounds phosphoric acid | N+P |
| 2. | 20 pounds nitrogen<br>20 pounds potash | N+K |
| 3. | 40 pounds phosphoric acid<br>20 pounds potash | P+K |
| 4. | 20 pounds nitrogen<br>40 pounds phosphoric acid<br>20 pounds potash | N+P+K |

None of the fertilizer materials used furnish important quantities of plant nutrients other than the three in question, except that the sulphate of potash supplies approximately 20 pounds per acre of sulphur trioxide and the dicalcic phosphate supplies about 25 pounds of calcium oxide. To avoid any possible shortage of calcium in the soil, and to at least partially overcome any soil acidity, a ton per acre of shell lime-

stone was applied to all plots in 1918 or 1919, and in 1922 a mixture of 2 tons calcite limestone and 1,000 pounds dolomitic limestone containing upwards of 20 per cent magnesium carbonate was applied. Beginning with 1922 sufficient land plaster to furnish the equivalent of the $SO_3$ content of the sulphate of potash has been applied to the plots which receive no potash. By increasing the size of the cropping units the number of fertilizer treatments may be increased. In later experiments, undertaken in other tobacco-growing sections, plots have been added to include a lime test and the effects of doubling the normal rate of the complete application and of omitting all fertilizer. The size of the present fertilizer plots is approximately one-fortieth acre.

the indicator crops on the control plots may be somewhat affected by the crops of neighboring plots. For these reasons the control plots have not given uniformly satisfactory evidence of relative productiveness in all cases, but for the most part the data are reasonably consistent. In the years 1916 and 1917 the complete fertilizer was applied at the normal rate to the cropping control plots on those fields which were occupied by the hoed crops, but no fertilizer has since been applied to the control plots.

### TOBACCO, POTATOES, AND CORN IN CONTINUOUS CULTURE AND IN ROTATION

This test, which was begun in 1916, requires only a single field. This is designated as Field I. The location

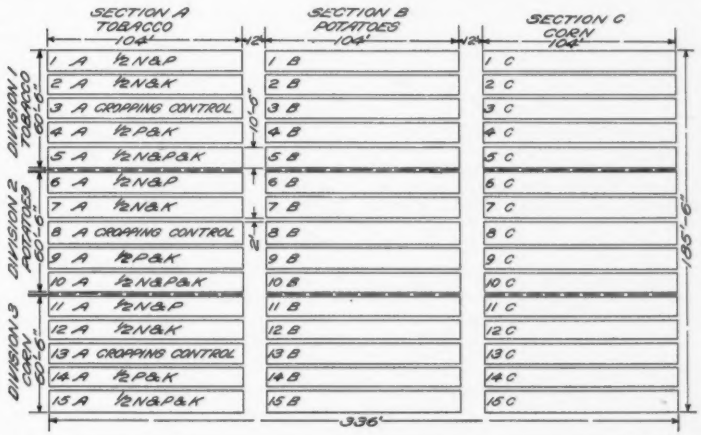



FIG. 4.—Plan of Field I, showing the dimensions of plots and intervening spaces, the fertilizer treatments, and the cropping system

### CONTROL PLOTS

In order that information may be had as to the comparative productiveness of different parts of the experimental fields, each cropping unit contains a "cropping control plot," which constitutes the middle plot of the unit. These control plots, of course, are cropped uniformly, tobacco and wheat having been used thus far as indicator crops, though it is now proposed to substitute corn for tobacco. If sufficient land were available, two control plots in each cropping unit would be desirable. It has been observed that different indicator crops may give different results as to relative productiveness of different plots. Also, it appears that under the conditions of the tests

and general plan of the field and the characteristics of the soil are shown on the soil map and accompanying report. The dimensions of the plots and intervening spaces, the fertilizer treatments and the cropping plan are shown in Figure 4.

In 1916 tobacco was grown on Section A, early potatoes on Section B, and corn on Section C. In 1917 tobacco was grown on Division I extending across the upper third of the three sections, potatoes were similarly grown on Division 2, and corn on Division 3. In 1918 the three crops were again grown on their respective sections, while in 1919 the boundaries of the crops again followed the boundaries of the divisions, and so on. It will be observed that tobacco is grown

every year on the block or cropping unit embraced in the first five plots of Section A (upper lefthand corner of fig. 4), this cropping unit being designated as A 1. Tobacco is grown in rotation with potatoes on Plots 6 to 10, inclusive, of Section A, and Plots 1 to 5, inclusive, of Section B, the tobacco crop occupying the first-named plots in even years and the last-named plots in odd years. Tobacco is grown in rotation with corn on the cropping units embracing the last five plots of Section A and the first five plots of Section C. Similarly, potatoes are grown every year on the central block of plots in Section B, and corn is grown every year on the cropping unit embracing Plots 11 to 15, inclusive, of Section C. Potatoes and corn are grown in rotation on the third division of Section B, embracing Plots 11 to 15, and on the second division of Section C, consisting of Plots 6 to 10.

The cropping control plots throughout the field (Plots 3, 8, and 13) are planted to tobacco every year The results on the control plots are summarized in Table IV. The plots are arranged in the table to accord with their actual position in the field, as shown in Figure 4. It appears that the productiveness of the field decreases somewhat from north to south and from west to east.

TABLE IV.—*Comparative productiveness of the cropping units of Field I as indicated by the average yields of tobacco on the control plots for the period 1916–1922, inclusive*

| Location of plot | Leaf, average yields per acre | | | Stalks, average yields per acre | | |
|---|---|---|---|---|---|---|
| | Plot 13 | Plot 8 | Plot 3 | Plot 13 | Plot 8 | Plot 3 |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* |
| Section A | 987 | 955 | 886 | 603 | 562 | 492 |
| Section B | 997 | 921 | 810 | 577 | 492 | 440 |
| Section C | 823 | 738 | 822 | 462 | 393 | 458 |

In 1916 the fertilizer materials were applied to the various plots at the standard rates, but in subsequent years only half the normal rates has been applied, as indicated in Figure 4. The Maryland Broadleaf type of tobacco has been used in these cropping tests as well as in those described later. The McCormick variety of potatoes was used in 1916, and in subsequent years the Irish Cobbler variety has been grown. The Boone County White variety of corn has been used in all the cropping tests of this group. Special effort has been made to insure satisfactory stands of the three crops on all plots. In practically all cases nearly perfect stands of tobacco have been obtained, although in some instances not all plants made sufficient growth to justify harvesting. In 1919 the number of plants actually harvested constituted about 92 per cent of a perfect stand where tobacco followed tobacco, 92 per cent where tobacco followed potatoes, and 90 per cent where tobacco followed corn. Similarly, where tobacco followed tobacco in 1920, 92 per cent of a stand was harvested, and in 1921, 80 per cent of a stand of tobacco was harvested after tobacco, 87 per cent after potatoes, and 90 per cent after corn. In all other cases the stand of tobacco harvested was 95 per cent or better. Practically perfect stands of potatoes were obtained in all instances. The same is true of corn, except that in 1917 the imature ears were damaged approximately 10 per cent by birds where corn followed corn, and in 1921 the stand on the same plots was about 91 per cent.

In comparing the three crops—tobacco, potatoes, and corn—it will be apparent that the valuable portions are, respectively, the leaf, tubers, and grain or seed, representative of three different features of plant growth. In the case of tobacco and corn, approximately the entire portion of the plant above ground is harvested, but this is not practicable for potatoes. Since no crop effects could be produced until the second year of the test, the crop yields of 1916 are not considered in this discussion. The average yields for the years 1917 to 1922, inclusive, under the different cropping combinations and different fertilizer treatments, are summarized in Table V. The tobacco crop of 1919 is not included in the averages because the buds of the young plants were severely injured by flea beetles and the results are not considered reliable.

The average yields of tobacco on the control plots in continuous culture, in rotation with potatoes, and in rotation with corn, are, respectively, 886,

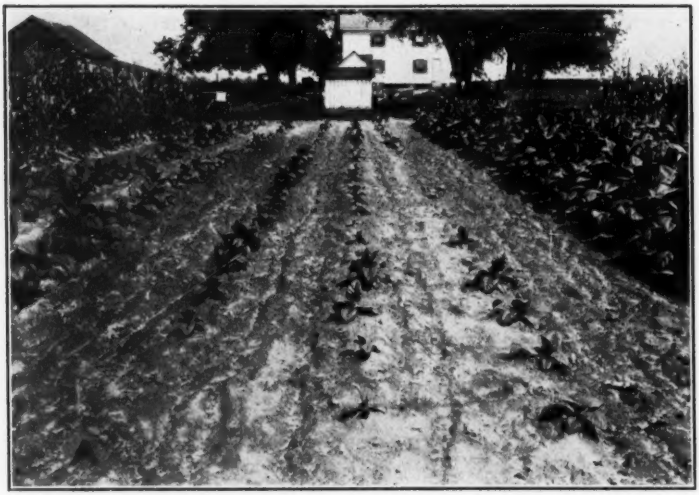
TABLE V.—*Summary of results with tobacco, potatoes, and corn on Field I for the years 1916–1922, inclusive, showing the comparative effects of each crop on yields of succeeding crops of tobacco, potatoes, and corn under different fertilizer treatments*

| Fertilizer treatment | Yield of tobacco leaf | | | | Yield of potatoes | | | | Yield of corn | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | After tobacco | After potatoes | After corn | Average | After tobacco | After potatoes | After corn | Average | After tobacco | After potatoes | After corn | Average |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* |
| ½(N+P) | 825 | 1,006 | 868 | 900 | 64.1 | 54.8 | 37.8 | 52.2 | 49.1 | 50.2 | 33.8 | 44.3 |
| ½(N+K) | 804 | 923 | 853 | 862 | 60.3 | 48.9 | 37.8 | 49 | 53.7 | 49.5 | 41.5 | 48.2 |
| ½(P+K) | 904 | 937 | 960 | 933 | 59.1 | 48.3 | 34 | 47.1 | 49.6 | 46.5 | 42.3 | 46.1 |
| ½(N+P+K) | 1,099 | 1,118 | 1,196 | 1,138 | 76.1 | 57.4 | 43.1 | 58.9 | 53.1 | 51.8 | 48.1 | 51 |
| Average | 908 | 996 | 969 | 958 | 64.9 | 52.4 | 38.2 | 51.8 | 51.4 | 49.5 | 41.4 | 47.4 |

| Fertilizer treatment | Yield of tobacco stalks | | | | Yield of corn stover | | | |
|---|---|---|---|---|---|---|---|---|
| | After tobacco | After potatoes | After corn | Average | After tobacco | After potatoes | After corn | Average |
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| ½(N+P) | 428 | 574 | 528 | 510 | 3,282 | 3,290 | 2,757 | 3,110 |
| ½(N+K) | 376 | 486 | 448 | 437 | 3,283 | 3,317 | 2,903 | 3,168 |
| ½(P+K) | 492 | 556 | 568 | 539 | 3,437 | 3,160 | 2,913 | 3,170 |
| ½(N+P+K) | 658 | 742 | 768 | 723 | 3,560 | 3,613 | 3,302 | 3,492 |
| Average | 489 | 590 | 578 | 552 | 3,391 | 3,345 | 2,969 | 3,235 |

883, and 905 pounds, indicating close agreement in productivity of the plots involved. It appears, therefore, that taking the average of all fertilizer treatments, continuous tobacco culture gives somewhat reduced yields as compared with tobacco after potatoes and after corn. As a matter of fact, there has been a progressive decrease in yield of tobacco under the continuous culture system, while good yields were obtained in the early years, so that the average result does not fully portray the situation. It is surprising that there is no substantial difference in yields of tobacco after potatoes and after corn. From the standpoint of parasitic disease as a factor, it will be recalled that tobacco and potatoes belong to the same family. From the standpoint of nutrition requirements, the corn crop removes much larger quantities of plant nutrients from the soil than does the potato crop. The omission of either nitrogen, phosphorus, or potassium from the fertilizer has materially reduced the yield, the omission of phosphorus having the greatest effect, and of nitrogen the least (pl. 5). The fertilizer effect has been greater than the crop effect, but the former does not overcome the latter. In view of the definite response to even the comparatively small additions of fertilizers made here, it is not clear why the potato crop does not produce a decided increase in yield of tobacco as compared with the effect of the corn crop. It may be added that for 1924, with a very wet spring, the growth of tobacco after corn has been very poor as compared with the growth after potatoes and after tobacco itself, especially where a complete fertilizer is not used. It may be, therefore, that earlier results will soon be reversed.

The yields of potatoes have been quite small, but some interesting differences have been obtained. Recalling the relationships between tobacco, potatoes, and corn as bearing on plant-disease factors and on comparative withdrawal of plant nutrients from the soil, it will be seen that the yield of potatoes is considerably better after tobacco than when potatoes are the preceding crop. On the other hand, continuous culture gives decidedly better yields than are obtained after corn. Moreover, the yield after tobacco is almost double that after corn. In this instance fertilizers apparently have not greatly influenced the result, the crop effects being much greater than the fertilizer effects. In continuous culture the tubers are severely affected with scab while there is little evidence of the disease after tobacco and corn. The average yields of tobacco on the control plots for potatoes in continuous culture and in rotation with tobacco and with corn are, respectively, 921, 883, and 868 pounds



A.—Growth of tobacco after corn on Field I in 1924. On center plot of three rows, potash is omitted from the fertilizer. On plot at left phosphorus is omitted from the fertilizer. Compare growth on these plots with that on the corresponding plots of tobacco after potatoes (B). Plot at right is tobacco after potatoes, the plot receiving a fertilizer supplying nitrogen, phosphorus, and potassium

B.—Growth of tobacco after potatoes on Field I in 1924. On center plot of three rows potash is omitted from the fertilizer. On plot at left phosphorus is omitted from the fertilizer. Growth of the tobacco is much better than after corn under similar conditions (A). Plot at right is tobacco after tobacco, the plot receiving nitrogen, phosphorus, and potassium in the fertilizer. The growth of tobacco, both after potatoes and after tobacco, is much better than after corn. The injurious effect of corn on the growth of tobacco is not always overcome by liberal fertilizing

per acre, indicating an approximately equal productiveness as a whole for the plots involved. The trend of the yields under the three cropping systems for the period covered is shown in Figure 5, which makes clear the progressive increase in yields after tobacco as compared with results after corn. The corn crop, which is in no wise related to potatoes, seems to produce an unfavorable influence on the production of tubers which is not materially modified by any of the fertilizer treatments used.

Good yields of corn have been maintained during the period of the tests, the yields of the last year being but little below those of the first. The average yields of tobacco on the control plots for corn in continuous culture, in rotation with tobacco and in rotation with potatoes, are, respectively, 823, 905, and 868 pounds of leaf, indicating that the productiveness of the plots occupied continuously by corn is somewhat less than the average of the plots occupied alternately by tobacco and corn. The data in Table IV indicate that this difference is due entirely to the superiority of the cropping unit represented by plot 13 of Section A over that represented by plot 13 of section C, the yields of the latter and of plot 3 of Section C being the same. It should be stated, also, that the differences in corn yields on the two cropping units have remained approximately constant from year to year. It seems probable that the reduced yields of corn in continuous culture are due at least in part to original lower productivity of the soil. Thus far the indications are that corn is less affected by preceding crops than tobacco and potatoes, although other crops are greatly affected by corn. In the rotations with tobacco and potatoes, the fertilizer treatments have had little effect on the corn crop, whereas in continuous corn culture the yields have been materially reduced by omission of each of the three elements from the fertilizer. Where the complete fertilizer mixture is used the differences in yields as between continuous culture and rotation are small and hardly significant.

As regards the bearing of these results on the plant-food theory and the theory of soil toxins, it might be expected, perhaps, that in comparison with the tobacco-cropping tests already discussed and the rotation tests which follow, the present series, which includes only hoed crops, would sooner or later involve more particularly the phenomenon of general soil exhaustion due to heavy annual withdrawals of plant nutrients. It is generally considered that soil toxins of vegetable origin are, for the most part, transitory products, so that intervals of several months each year when the soil is not occupied by the crops, such as occur in this series, would tend to reduce injurious effects on succeeding crops from this cause. Moreover, broadly speaking, the toxic effects of any particular crop tend to become evident in the early years of cropping, and these

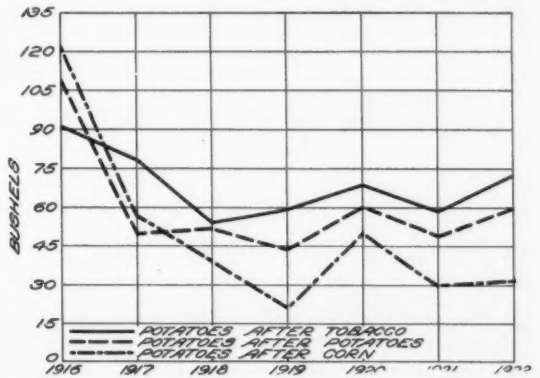



FIG. 5.—Comparative effects of tobacco, potatoes, and corn, as preceding crops, on the yield of potatoes. The "crop effects" evidently are influenced by seasonal conditions, but the yield of potatoes has been somewhat better after tobacco than after potatoes, and much better after tobacco than after corn. It appears that these differences are increasing. The yields here shown are the averages of all fertilizer treatments

effects would be cumulative only to a limited degree. However, depletion of plant nutrients ordinarily would be essentially progressive over relatively long periods and might first become of importance after several years' cropping. So far, the expectations just mentioned seem to have been realized in part, but there are important exceptions. Certain of the crop effects are not influenced at all or are only partly overcome by the fertilizer treatments used and are not in accord with the facts as to comparative withdrawals of plant nutrients by the different crops. It will be of interest to ascertain the result of continued soil depletion by prolonged cropping for comparison with the more immediate crop effects which do not seem to be explainable by the plant-food theory alone. No definite conclusion can be reached at this time as to the true nature of these latter effects.

## TOBACCO, POTATOES, AND CORN IN ROTATION WITH WHEAT, OATS, AND RYE

These cropping systems constitute the second step in testing the fundamental value of the general type of rotation under study and should bring out the relative merits of the various possible combinations of these two groups of crops. In this series a deep-rooted crop regularly alternates with a shallow-rooted crop. Mention was made in the preceding series of the fact that tobacco and potatoes belong to the same family, and in the present tests it is well to keep in mind that corn is similarly related to wheat, oats, and rye. There is a comparatively long interval between the harvest of the small grain crops and the planting of the hoed crops which follow, the soil thus remaining unoccupied for nearly 12 months. The small grains, on the other hand, are seeded almost immediately after harvest of the hoed crops.

The general plan of the cropping tests and the fertilizer treatments are quite similar to those used in the preceding tests, except that two fields are employed instead of one in order that all crops may be grown each year. The fields are numbered II and III. Beginning with 1914 on Field II, tobacco, potatoes, and corn have been grown in even years, and wheat, oats, and rye in odd years. On Field III, beginning with 1915, the hoed crops have been grown in odd years and the small grains in even years. The location of the fields and the general characteristics of the soil are shown on the soil map and accompanying report (p. 1199). The detailed plans of Field II, the cropping system, and the fertilizer treatments are shown in Figure 6. The plan and treatments of Field III are the same, except that the dimensions of the plots differ slightly from those of Field II. As in the experiments previously described, tobacco is grown on Section A, potatoes on Section B, and corn on Section C. Following these crops, wheat is seeded on Division 1, embracing the first five plots of Sections A, B, and C. Similarly, oats are seeded on Division 2, extending across the three sections and embracing Plots 6, 7, 9, and 10, Plot 8 being a control; and rye is seeded on Division 3, embracing Plots 11, 12, 14, and 15 of the three sections, Plot 13 being a control.

Maryland Broadleaf tobacco, Irish Cobbler potatoes, and Boone County White corn have been used in the tests. For the winter small grains Currell's Prolific wheat, Culberson oats, and local seed of winter rye have been used. The rates of seeding have been 2 bushels of oats and 1½ bushels of wheat and rye per acre. As indicated in Figure 6, the fertilizers have been applied to the hoed crops at the normal rates throughout the tests. The first crop of wheat, oats, and rye on both fields received no fertilizer, but all subsequent crops of small grains have received one-half the normal rates applied to the hoed crops. Liming has been the same as on Field I. There has been very little winter killing of rye and wheat, but in a few instances oats have been somewhat damaged by this factor, the injury being mostly limited to oats after corn where but little fall growth had been made. During the first three years of the experiments, considerable injury to wheat resulted from joint worm, but subsequently this has been avoided by plowing under the grain stubble shortly after harvest and removing all wheat straw from the farm immediately after threshing.

Each year the stand of potatoes on both fields has been nearly perfect. On Field II the tobacco crop of 1922 was practically a failure because of the wildfire and mosaic diseases and has not been included in tabulating the average yields. In 1916, 1918, and 1920 the stands of tobacco on the three cropping units of Field II ranged from 85 to 96 per cent, and the differences in any year did not exceed 6 per cent. On Field III the stands of tobacco have been 95 per cent or better.

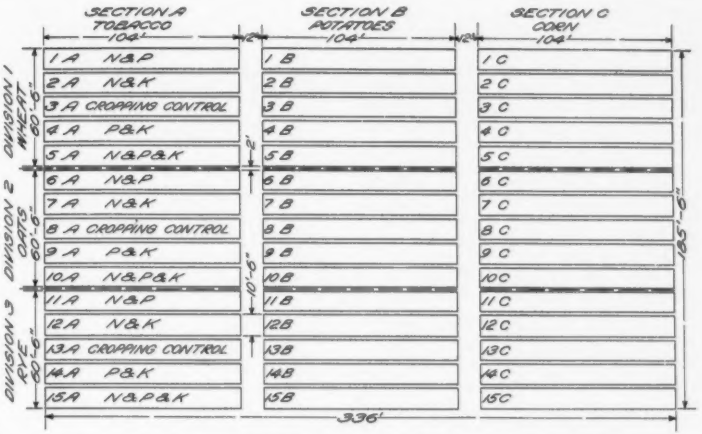



FIG. 6.—Plan of Field II, showing the arrangement and dimensions of plots and intervening spaces, the fertilizer treatments, and the cropping system

TABLE VI.—*Comparative productiveness of the cropping units of Field II as indicated by the average yields of tobacco and wheat on the control plots for the period 1915 to 1923, inclusive*

| Location of plot | Tobacco | | | | | | Wheat | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yields of leaf, per acre | | | Yields of stalks, per acre | | | Yields of grain, per acre | | | Yields of straw, per acre | | |
| | Plot 13 | Plot 8 | Plot 3 | Plot 13 | Plot 8 | Plot 3 | Plot 13 | Plot 8 | Plot 3 | Plot 13 | Plot 8 | Plot 3 |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bush.* | *Bush.* | *Bush.* | *Lbs.* | *Lbs.* | *Lbs.* |
| Section A | 756 | 853 | 880 | 408 | 488 | 497 | 7.5 | 9.4 | 12.0 | 870 | 1,058 | 1,245 |
| Section B | 745 | 763 | 895 | 421 | 429 | 449 | 9.3 | 10.3 | 13.8 | 975 | 1,255 | 1,410 |
| Section C | 719 | 640 | 952 | 407 | 368 | 545 | 7.0 | 8.6 | 12.0 | 773 | 975 | 1,240 |

TABLE VII.—*Comparative productiveness of the cropping units of Field III as indicated by the average yields of tobacco and wheat on the control plots for the period 1916 to 1922*

| Location of plot | Tobacco | | | | | | Wheat | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yields of leaf, per acre | | | Yields of stalks, per acre | | | Yields of grain, per acre | | | Yields of straw, per acre | | |
| | Plot 13 | Plot 8 | Plot 3 | Plot 13 | Plot 8 | Plot 3 | Plot 13 | Plot 8 | Plot 3 | Plot 13 | Plot 8 | Plot 3 |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bush.* | *Bush.* | *Bush.* | *Lbs.* | *Lbs.* | *Lbs.* |
| Section A | 1,076 | 1,122 | 1,082 | 626 | 698 | 604 | 9.4 | 9.8 | 10.8 | 1,225 | 1,344 | 1,545 |
| Section B | 931 | 906 | 973 | 469 | 466 | 458 | 7.7 | 8.7 | 9.8 | 1,299 | 1,216 | 1,592 |
| Section C | 844 | 859 | 863 | 445 | 465 | 397 | 10.0 | 9.7 | 10.5 | 1,317 | 1,363 | 1,476 |

The stand of corn has been excellent on both fields. On Field III the immature ears of corn were badly damaged by birds in 1915 and the yields of grain were computed on the data from uninjured plants constituting 50 to 60 per cent of the total. Stands of small grains have been uniformly good.

The arrangement of cropping control plots is the same as for Field I. Those of Field II received the complete fertilizer at the normal rate in 1916 and 1918, and those of Field III were similarly treated in 1915 and 1917. In other years no fertilizers have been applied to these plots. The control plots throughout the two fields have been cropped in tobacco and wheat in regular rotation. The average yields are summarized in Tables VI and VII. Because of serious injury from joint worm the yields of wheat on Field III in 1918 are not included in the averages.

One of the facts brought out in Tables VI and VII which should be mentioned is that tobacco and wheat as indicators of relative productivity of different soil areas do not always give similar results. Thus, the yields of wheat on Field II indicate a greater superiority in productiveness of Division 1, as represented by Plot 3, over Divisions 2 and 3, represented by Plots 8 and 13, than is indicated by the yields of tobacco on the same plots. Again, on Field III the yields of tobacco would indicate that Section A as a whole is considerably more productive than Section C. This is contrary to the results with wheat, and the general lay of the land and the character of the soil indicate that for most staple crops Section C is at least equal, if not superior to Section A in productivity. Under the circumstances it seems logical to depend primarily on results with wheat in dealing with small grains, but to rely more on results with tobacco in considering the hoed crops.

The average results obtained on Fields II and III with the small grains after each of the three hoed crops are summarized in Table VIII. In this table it is a simple matter to compare the effects of the different hoed crops on each of the small-grain crops and also compare these crop effects with the effects of the different fertilizer treatments.

Taking first the wheat crop, the average yields of wheat on the control plots for the wheat division (Plot 3) of Sections A, B, and C of the two fields are 11.4, 11.8, and 11.3 bushels, respectively, indicating substantial uniformity in productivity of the cropping units involved. It appears, therefore, that corn has had a decidedly depressing action on yield of both grain and straw of wheat, while there is only a slight difference in the effects of tobacco and potatoes. These relations hold true under all the fertilizer treatments used. The fertilizer treatments also clearly affect the yields of wheat, omission of phosphorus having a markedly depressing action. It is interesting to note that although the fertilizer treatments influence the wheat yields in any particular case, they show no well-defined tendency to overcome the differences in effects of the preceding crops of tobacco, potatoes, and corn.

Turning to the oats crop, the average yields of wheat on the control plots for the oats division (Plot 8) of the sections of the two fields occupied respectively by tobacco, potatoes, and corn are 9.6, 9.5, and 9.2 bushels. These yields stand at a somewhat lower level than those for the wheat division of the fields, already discussed, but these yields agree satisfactorily among themselves, indicating approximate uniformity in productivity of the cropping units occupied by oats. Here, again, the depressing effect of corn on the yields of oats is noticeable, and there is also an appreciable gain in yield after potatoes as compared with the yield after tobacco. The fertilizer treatments have affected the yields, but these effects are not sharply defined in all cases. In this instance omission of nitrogen from the fertilizer rather than phosphorus has had the greatest depressing effect, although after corn omission of phosphorus seems to be of significance. As in the case of wheat, the fertilizer treatments do not accomplish much in overcoming the differences in effects of the three preceding hoed crops.

Considering finally the rye crop, the average yield of wheat on the control plots of the rye division (Plot 13) of the two fields is 8.5 bushels alike for the tobacco, potatoes, and corn sections. Potatoes as a preceding crop seem to favor the growth of rye, the yields of both grain and straw being markedly increased as compared with results after tobacco and corn. The yields after tobacco are only slightly better than those after corn, but the differences seem to be appreciably influenced by the fertilizer treatment. When potassium or phosphorus are omitted from the fertilizer, the differences in yield after tobacco and after corn are increased. With tobacco as the preceding crop, nitrogen seems to be the chief plant nutrient limiting yields,

TABLE VIII.—*Summary of results with small grains in Fields II and III for the years 1915 to 1923, inclusive, showing the comparative effects of tobacco, potatoes, and corn as preceding crops on the yields of wheat, oats, and rye under different fertilizer treatments; also, the effects of the fertilizer treatments on the yields of wheat, oats, and rye*

| Fertilizer treatment | Yield of wheat | | | | Yield of oats | | | | Yield of rye | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | After tobacco | After potatoes | After corn | Average | After tobacco | After potatoes | After corn | Average | After tobacco | After potatoes | After corn | Average |
| | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* |
| ½ (N+P) | 14.4 | 14.1 | 9.5 | 12.7 | 21 | 24.2 | 16.1 | 20.4 | 15.8 | 19.8 | 13.2 | 16.3 |
| ½ (N+K) | 10.1 | 9.2 | 6.6 | 8.6 | 19.4 | 22.7 | 12.8 | 18.3 | 14.3 | 17.3 | 12.1 | 14.6 |
| ½ (P+K) | 12.0 | 13.9 | 9.0 | 11.6 | 15.7 | 18.8 | 12.9 | 15.8 | 11.3 | 16.7 | 12.6 | 13.5 |
| ½ (N+P+K) | 12.7 | 13.9 | 9.1 | 11.9 | 16.7 | 20.9 | 14.4 | 17.3 | 14.1 | 20.5 | 14.6 | 16.4 |
| Average | 12.3 | 12.8 | 8.6 | 11.2 | 18.2 | 21.6 | 14.1 | 18.0 | 13.9 | 18.6 | 13.1 | 15.2 |

| Fertilizer treatment | Yield of wheat straw | | | | Yield of oats straw | | | | Yield of rye straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* |
| ½ (N+P) | 1,648 | 1,765 | 1,038 | 1,484 | 855 | 1,069 | 751 | 892 | 2,061 | 2,597 | 1,551 | 2,070 |
| ½ (N+K) | 1,208 | 1,207 | 753 | 1,056 | 858 | 971 | 580 | 803 | 1,731 | 2,191 | 1,398 | 1,773 |
| ½ (P+K) | 1,235 | 1,611 | 930 | 1,259 | 726 | 814 | 551 | 697 | 1,552 | 2,357 | 1,371 | 1,760 |
| ½ (N+P+K) | 1,427 | 1,639 | 1,018 | 1,361 | 778 | 912 | 631 | 774 | 1,725 | 2,651 | 1,819 | 2,065 |
| Average | 1,379 | 1,555 | 935 | 1,290 | 804 | 942 | 628 | 791 | 1,768 | 2,449 | 1,535 | 1,917 |

while with potatoes and corn as preceding crops nitrogen and phosphorus seem to be of about equal importance. In general, the differences in yield under the different fertilizer treatments are not as great as might be expected.

Summarizing, it appears that corn, in comparison with tobacco and potatoes, has a depressing effect on the yields of wheat, oats, and rye. Compared with tobacco, corn shows the greatest depressing action on wheat and the least on rye. Compared with potatoes, corn reduces the yields of wheat, oats, and rye about the same extent. After tobacco the yield of wheat is about the same as after potatoes, the yield of oats is reduced less than 20 per cent, while the yield of rye is reduced by about a third. These crop effects are not greatly modified by the different fertilizer treatments used. Why the effects of tobacco more nearly resemble those of potatoes rather than those of corn is not clear from the standpoint of the plant-food theory.

The comparative effects of tobacco, potatoes, and corn on each of the small grains for each year as well as the general trend of these crop effects are shown graphically in Figures 7, 8, and 9. The yields shown are the combined weights of grain and straw, and are the averages of all fertilizer treatments. For the most part there is a notable similarity in yields of wheat after tobacco and after potatoes, but in certain years production is much greater after potatoes than after tobacco. On the other hand, with a single exception, the relative growth of wheat after corn is decidedly reduced each year, and in some years the differences are very large. In the earlier years of the test, oats usually gave considerably better results after potatoes than after the other two crops, and the yields after tobacco and corn were about the same, except in 1915. In recent years, however, yields after tobacco have more nearly equaled those after potatoes. Throughout the test, the growth of rye after tobacco has been closely similar though somewhat superior to that after corn. Potatoes as a preceding crop greatly stimulated the growth of rye at first, but in later years this advantage has not been maintained. It is of interest to note that there has been no progressive decline in yields of any of the small grains, even after corn.

The average results with tobacco, potatoes, and corn after the three small grains on Fields II and III are summarized in Table IX. The average yields of tobacco on corresponding control plots of the two fields indicate comparative uniformity in productiveness of the three cropping units of the tobacco sections, while in the potato and corn sections the cropping units occupied by wheat seem to be some-

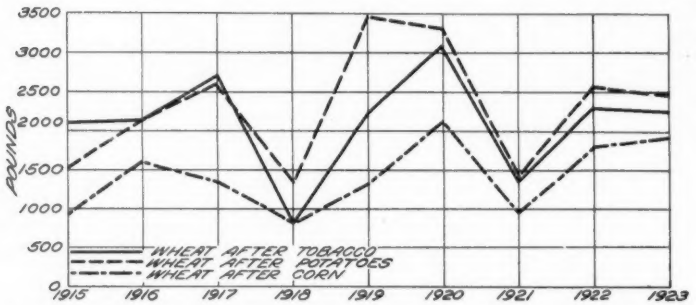



FIG. 7.—Comparative effects of tobacco, potatoes, and corn as preceding crops on the yield of wheat. The comparative results are affected by the seasonal conditions, but in most years the yields after tobacco have not differed greatly from those after potatoes. After corn the yields are lower—frequently much lower—than after tobacco and potatoes. The yields recorded are the combined weights of grain and straw.

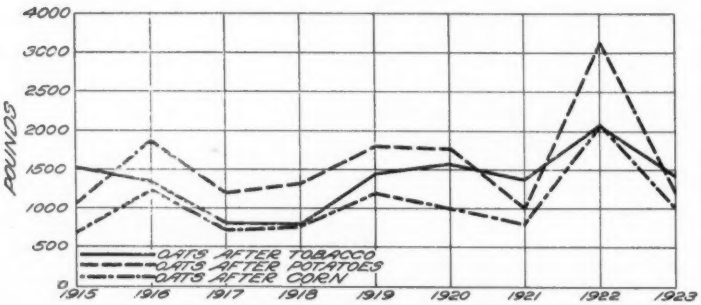



FIG. 8.—Comparative effects of tobacco, potatoes, and corn as preceding crops on the yield of oats. Here, again, the lowest yields are after corn. The yields generally lie between those after potatoes and after corn. The yields recorded are the combined weights of grain and straw

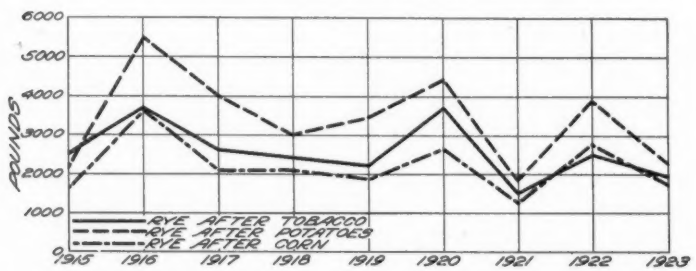



FIG. 9.—Comparative effects of tobacco, potatoes, and corn as preceding crops on the yield of rye. The rye at first seems to thrive particularly well after potatoes, but subsequently the yield more nearly approaches the yields following tobacco and corn. There is less difference in yields of rye after the lattter two crops than in the case of wheat and oats, though the results after tobacco are somewhat better than those after corn. The yields are expressed as the combined weights of grain and straw

what more productive than those occupied by oats and rye. These latter differences are due to apparent soil variation in Field II, there being no substantial differences in yields of the three control plots in any of the sections of Field III. As a whole, the differences in effects of the three small grain crops on the hoed crops are comparatively small, possibly because there is a rather long interval between the time of harvest of the former and planting of the latter, coupled with the fact that the small grains are shallow-rooted crops. As to tobacco, there seems to be no difference in the effects of wheat and oats as preceding crops. Taking the average of all fertilizer treatments as shown in Figure 10, the tobacco yields after the two crops have agreed closely each year on the two fields. Rye, as compared with wheat and otas, appears to have a depressing effect which is not overcome or greatly modified by any of the fertilizer treatments, except that on Field III the complete fertilizer does overcome this effect. There is some indication in Figure 10 that this effect is progressive. Of the three fertilizing elements, nitrogen seemed to have the greatest effect on the yield of tobacco, while potassium has seemed to have had little effect.

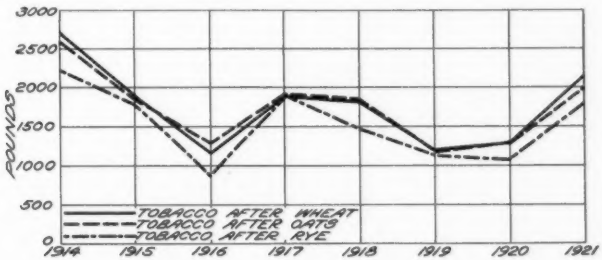



FIG. 10.—Comparative effects of wheat, oats, and rye as preceding crops on the yield of tobacco. In general the differences in effects of the small grains on the hoed crops are not great. The yields of tobacco after wheat and after oats closely agree each year. Rye, in comparison, shows a slight depressing effect. The yields are expressed as the combined weights of leaf and stalk

TABLE IX.—*Summary of results with hoed crops on Fields II and III for the years 1916 to 1922, inclusive, showing the comparative effects of wheat, oats, and rye as preceding crops on the yields of tobacco, potatoes, and corn, under different fertilizer treatments; also, the effects of the fertilizer treatments on the yields of tobacco, potatoes, and corn.*

| Fertilizer treatment | Yield of tobacco leaf | | | | Yield of potatoes | | | | Yield of corn | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | After wheat | After oats | After rye | Average | After wheat | After oats | After rye | Average | After wheat | After oats | After rye | Average |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* |
| N+P | 1,122 | 1,053 | 912 | 1,029 | 64.1 | 54.1 | 50.8 | 56.3 | 43.9 | 38.9 | 33.4 | 38.7 |
| N+K | 1,042 | 959 | 939 | 980 | 48 | 42.5 | 39.1 | 43.2 | 42.1 | 35.8 | 35.7 | 37.9 |
| P+K | 861 | 914 | 750 | 842 | 53.1 | 48.3 | 39.6 | 47 | 35.9 | 31.4 | 26.6 | 31.3 |
| N+P+K | 1,091 | 1,087 | 959 | 1,046 | 72 | 69.4 | 57.8 | 66.4 | 38.4 | 35.7 | 34.7 | 36.3 |
| Average | 1,029 | 1,003 | 891 | 974 | 59.3 | 53.6 | 46.8 | 53.2 | 40.1 | 35.5 | 32.6 | 36.1 |

| Fertilizer treatment | Yield of tobacco stalks | | | | Yield of corn stover | | | |
|---|---|---|---|---|---|---|---|---|
| | After wheat | After oats | After rye | Average | After wheat | After oats | After rye | Average |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* |
| N+P | 645 | 629 | 516 | 597 | 3,172 | 2,783 | 2,533 | 2,829 |
| N+K | 544 | 551 | 521 | 539 | 2,903 | 2,404 | 2,429 | 2,579 |
| P+K | 457 | 498 | 357 | 437 | 2,515 | 2,298 | 2,250 | [1] 354 |
| N+P+K | 648 | 686 | 562 | 632 | 2,975 | 2,755 | 2,769 | 2,833 |
| Average | 573 | 591 | 488 | 551 | 2,891 | 2,560 | 2,496 | 2,649 |

The yields of potatoes are small and it is doubtful if the apparent crop effects are significant. Phosphorus and nitrogen are the most significant fertilizing elements. The yields of corn on Field II have rapidly declined in later years after oats and especially after rye, but this result is probably due in part to original differences in productiveness of the soil. On Field III no differences have developed thus far in the effects of wheat, oats, and rye on the yields of corn. Nitrogen is the important fertilizing element in the corn yields.

ments being applied. The two fields used are IV and V. The location and the general characteristics of the soil of the two fields are shown on the soil map and accompanying report. The plan of Field IV, together with the detailed system of cropping, are shown in Figure 11. The plan of Field V is the same in all respects, except that lack of a sufficiently large area of suitable soil made it necessary to locate the rye division apart from the remainder of the field and immediately adjacent to Field IV, as shown on the soil map.

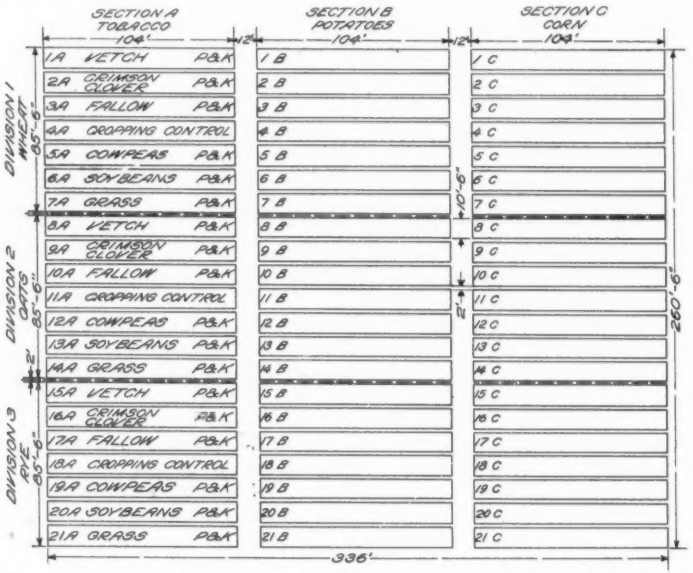



FIG. 11.—Plan of Field IV showing the arrangement and dimensions of the plots and intervening spaces and the cropping system followed. The grass and legumes are used as soiling crops

## TOBACCO, POTATOES, AND CORN IN ROTATION WITH SMALL GRAINS AND LEGUMES

Addition of legumes to the cropping systems last discussed constitutes the final step in testing the value of the type of rotation under study and should throw more light on the relative merits of the several possible combinations of hoed crops and small grains included in the tests. These tests are essentially repetitions of the previously described tests with hoed crops in rotation with small grains, with the important difference that grass and various legumes are grown as soiling crops on the plots of each cropping unit instead of different fertilizer treatments being applied. The two fields used are IV and V. The location and the general characteristics of the soil of the two fields are shown on the soil map and accompanying report. The plan of Field IV, together with the detailed system of cropping, are shown in Figure 11. The plan of Field V is the same in all respects, except that lack of a sufficiently large area of suitable soil made it necessary to locate the rye division apart from the remainder of the field and immediately adjacent to Field IV, as shown on the soil map.

As in the preceding tests, tobacco, potatoes, and corn are grown in parallel strips, followed by wheat, oats, and rye seeded crosswise these strips. Each of the nine cropping units thus formed is subdivided into seven plots, of which one is used as a cropping control. Of the remaining plots, one receives no additional crop, while the others are seeded to hairy vetch, crimson clover, cowpeas, soy beans, and a grass mixture, respectively. In this way the effects of two summer legumes and two winter legumes as annual soiling crops are compared with a non-leguminous soiling crop and with fallowing. The summer legumes are planted shortly after harvesting the small grains and the other soiling crops

are seeded in early fall. All plots are fertilized uniformly, with the precipitated dicalcic phosphate and sulphate of potash at the standard rates of 40 pounds phosphoric acid and 20 pounds potash per acre, respectively, for the hoed crops, and beginning with 1918, one-half these rates have been applied each year to the small grains. No nitrogen is applied to any of the plots. Liming has been the same as on Fields II and III.

Tobacco, potatoes, and corn follow directly after the soiling crops, while the small grains are subject only to the residual effects of the soiling crops. As a nonleguminous cover crop a mixture of timothy, tall meadow oat, and orchard and Italian rye grass is used. Beginning with 1916 the hoed crops have been grown on Field IV in even years and on Field V in odd years. Legumes were first seeded on Field IV in 1917 after the small grains, and on Field V they were planted in 1916 in preparation for the first crops of tobacco, potatoes, and corn. Only the cowpeas showed effective inoculation in the crop of the first year, but all legumes have made good growth since the first year. Stands of the various crops have been satisfactory in nearly all cases.

The arrangement and treatment of cropping control plots are the same as for Fields II and III, and tobacco and wheat have been regularly grown in rotation on the plots. The average yields are shown in Tables X and XI. The data for wheat in 1918 on Field V are unreliable, because of damage from joint worm, and are not included in the averages. As was found to be true on Fields II and III, the data in these tables disclose several instances in which tobacco and wheat as indicators of relative soil productiveness give contradictory results. The most striking case is that of the rye division of Field V, represented by Plot 18 of the three sections, as compared with Plots 11 and 4, representing the oats and wheat divisions, respectively. The results with tobacco indicate that the rye division is the more productive, but the yields of wheat on the control plots are much lower than on the control plots of the oats and wheat divisions. On the whole, Field IV seems to be comparatively uniform except that the tobacco-rye cropping unit represented by Plot 18 is undoubtedly somewhat less productive than the remainder of the field. On Field V the contradictory results as to the rye division have been mentioned already. The results with tobacco and wheat agree in indicating that the corn section (C) is some 20 to 25 per cent less productive than the remainder of Field V.

TABLE X.—*Comparative productiveness of the cropping units of Field IV as indicated by the average yields of tobacco and wheat on the control plots for the period 1916–1922, inclusive*

| Location of plot | Tobacco | | | | | | Wheat | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yields of leaf per acre | | | Yields of stalks per acre | | | Yields of grain per acre | | | Yields of straw per acre | | |
| | Plot 18 | Plot 11 | Plot 4 | Plot 18 | Plot 11 | Plot 4 | Plot 18 | Plot 11 | Plot 4 | Plot 18 | Plot 11 | Plot 4 |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bush.* | *Bush.* | *Bush.* | *Lbs.* | *Lbs.* | *Lbs.* |
| Section A | 891 | 1,025 | 1,035 | 520 | 624 | 659 | 10.3 | 13.2 | 14 | 1,303 | 1,873 | 1,507 |
| Section B | 1,110 | 1,143 | 1,100 | 655 | 700 | 775 | 14 | 12 | 13.7 | 2,123 | 1,927 | 1,767 |
| Section C | 950 | 813 | 899 | 610 | 606 | 698 | 12.7 | 13.3 | 16.3 | 1,807 | 1,790 | 1,933 |

TABLE XI.—*Comparative productiveness of the cropping units of Field V as indicated by the average yields of tobacco and wheat on the control plots for the period 1917–1922, inclusive*

| Location of plot | Tobacco | | | | | | Wheat | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yield of leaf per acre | | | Yield of stalks per acre | | | Yield of grain per acre | | | Yield of straw per acre | | |
| | Plot 18 | Plot 11 | Plot 4 | Plot 18 | Plot 11 | Plot 4 | Plot 18 | Plot 11 | Plot 4 | Plot 18 | Plot 11 | Plot 4 |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bush.* | *Bush.* | *Bush.* | *Lbs.* | *Lbs.* | *Lbs.* |
| Section A | 1,041 | 869 | 916 | 450 | 422 | 458 | 9.8 | 15.8 | 17.8 | 980 | 1,600 | 1,810 |
| Section B | 1,017 | 721 | 842 | 497 | 381 | 394 | 10 | 17.5 | 17.5 | 1,050 | 2,190 | 1,930 |
| Section C | 754 | 713 | 696 | 460 | 365 | 407 | 8.5 | 11.8 | 14.8 | 850 | 1,150 | 1,360 |

Summaries of the results with tobacco, potatoes, and corn on Fields IV and V are given in Table XII. Two features are of interest, namely: (1) The comparative effects of preceding crops of wheat, oats, and rye as modified by the intervening soiling crops; and (2) the comparative, direct effects of the soiling crops on tobacco, potatoes, and corn. As to the first-named feature, the results with tobacco are quite similar to those obtained in the preceding tests where no soiling crops were used. Although the differences in effects of wheat, oats, and rye are not large, these differences seem to be significant, particularly as to the depressing effect of rye on the yields of tobacco. Thus, in 1917, the first year of the test, the average yield of tobacco on the rye division of Field V was 1,340 pounds per acre and on the wheat division the yield was 1,320 pounds. In 1921 the corresponding yields were 1,008 pounds and 1,245 pounds per acre. The general effect of the intervening legumes has been to intensify the relatively unfavorable effect of rye on the growth of tobacco. Grass as a soiling crop, on the other hand, seems to act in the reverse manner, giving somewhat better results after rye than after wheat. These effects of the legumes are associated with a tendency toward increased yields of tobacco, while the effects of grass are associated with decreased yields.

The direct effects of the soiling crops on tobacco are interesting in several particulars. For the comparatively short period of the tests, vetch, crimson clover, and cowpeas as soiling crops have given rather large increases of tobacco where wheat was the preceding crop, just as was the case in the early years of the special cropping tests with tobacco which have already been discussed. With rye as the preceding crop, and to a lesser extent with oats, these legumes have been much less effective in increasing the yield of tobacco. Of the four legumes, soy beans are unique in that they are wholly ineffective in all cases in promoting the growth of tobacco and in some instances have actually decreased the tobacco yield. Grass as a soiling crop has had a remarkable depressing action on the growth of tobacco, the yields of which are reduced to nearly half those of the fallow plots. These relationships are brought out in more detail in Figure 12.

TABLE XII.—*Summary of results with hoed crops on Fields IV and V for the years 1918–1922, inclusive, showing the comparative effects of wheat, oats, and rye as preceding crops on the yields of tobacco, potatoes, and corn, when soiling crops intervene in the rotation; also the comparative effects of the soiling crops on the yields of tobacco, potatoes, and corn*

| Soiling crop grown | Yield of tobacco leaf | | | | Yield of potatoes | | | | Yield of corn | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | After wheat | After oats | After rye | Average | After wheat | After oats | After rye | Average | After wheat | After oats | After rye | Average |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* |
| Vetch | 1,352 | 1,041 | 858 | 1,084 | 74.8 | 56.1 | 53.1 | 61.3 | 59.1 | 59.9 | 53.4 | 57.5 |
| Crimson clover | 1,410 | 1,181 | 969 | 1,187 | 77.8 | 52.5 | 51.5 | 60.6 | 59.9 | 54.9 | 49.5 | 54.8 |
| Fallow | 920 | 999 | 799 | 906 | 59.8 | 51.6 | 46.4 | 52.6 | 41.4 | 42.9 | 42.0 | 42.1 |
| Cowpeas | 1,321 | 1,299 | 1,156 | 1,259 | 71.1 | 60 | 65.9 | 65.7 | 58.0 | 53.5 | 55.8 | 55.8 |
| Soy beans | 938 | 822 | 846 | 869 | 54.1 | 45.8 | 52.1 | 50.7 | 54.5 | 49.5 | 54.4 | 52.8 |
| Grass | 489 | 668 | 563 | 573 | 38.7 | 31.2 | 39.5 | 36.5 | 37.8 | 35.1 | 42.5 | 38.5 |
| Average | 1,071 | 1,002 | 865 | 979 | 62.7 | 49.5 | 51.4 | 54.6 | 51.8 | 49.3 | 49.6 | 50.2 |

| Soiling crop grown | Yield of tobacco stalks | | | | Yield of corn stover | | | |
|---|---|---|---|---|---|---|---|---|
| | After wheat | After oats | After rye | Average | After wheat | After oats | After rye | Average |
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* |
| Vetch | 784 | 499 | 404 | 562 | 4,290 | 4,120 | 3,635 | 4,015 |
| Crimson clover | 776 | 595 | 493 | 621 | 4,287 | 3,899 | 3,470 | 3,885 |
| Fallow | 514 | 517 | 369 | 467 | 3,230 | 3,207 | 2,962 | 3,133 |
| Cowpeas | 729 | 657 | 624 | 670 | 3,930 | 3,744 | 3,914 | 3,863 |
| Soy beans | 468 | 392 | 403 | 421 | 3,643 | 3,349 | 3,685 | 3,559 |
| Grass | 219 | 304 | 249 | 257 | 2,605 | 2,597 | 3,001 | 2,734 |
| Average | 582 | 494 | 424 | 500 | 3,664 | 3,486 | 3,443 | 3,531 |

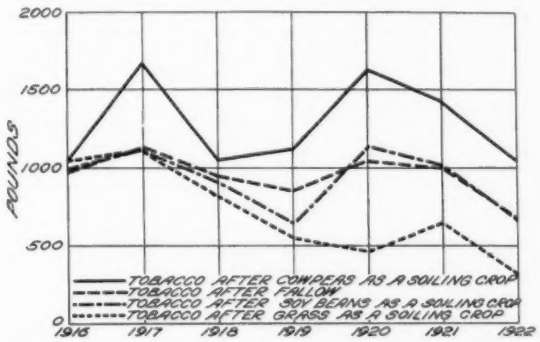



FIG. 12.—Effects of cowpeas, soy beans, and grass as soiling crops on the average yield of tobacco in the rotations with wheat, oats, and rye. For the comparatively short period covered, cowpeas show a favorable, though variable, effect on the growth of tobacco. Soy beans, on the other hand, have failed from the outset to produce decided increase in growth and in some years they have actually depressed the yield. Grass as a cover crop has caused a marked downward trend in the tobacco yield

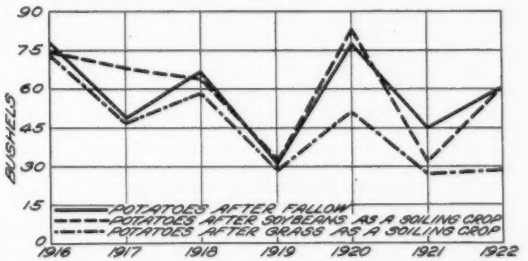



FIG. 13.—Effects of soy beans and grass as soiling crops on the average yield of potatoes in the rotations with wheat, oats, and rye. The results are similar to those with tobacco, as shown in Figure 12. Soy beans in the beginning showed a beneficial effect on potatoes, but in later years the effect has been either nil or injurious. Grass as a cover crop has resulted in a decided downward trend in yield of potatoes

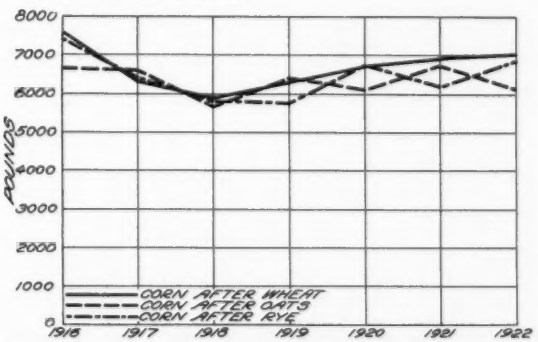



FIG. 14.—Comparative effects of wheat, oats, and rye on the corn crop when intervening soiling crops are included in the rotations. There is a notable similarity in the effects of the three small grains, although, on the whole, wheat appears to exert a somewhat more favorable action than oats or rye. The upward trend in yield since 1918 is considered due to the action of the soiling crops. This result differs from the results with tobacco and potatoes shown in part in Figures 12 and 13. The yields of corn are the combined weights of grain and straw

In the case of potatoes, the results generally are similar to those with tobacco except that, as compared with wheat, oats as well as rye have a depressing effect on yields. Vetch, crimson clover, and cowpeas are of little value in increasing the yields of potatoes when either oats or rye is the preceding crop. Soy beans have failed to increase yields even with wheat as the preceding crop. Grass has greatly depressed the potato yields in all cases. The effects of soy beans and grass on the yields of potatoes are shown graphically in Figure 13. There are no significant general differences in yields of corn with wheat, oats, and rye as preceding crops, and legumes generally are effective in increasing the yield. The similarity in effects of the three small grains are shown in graphic form in Figure 14. Soy beans give almost as good results as the other legumes. Grass depresses yield, but to a lesser extent than is the case with tobacco and potatoes.

Some of these results are difficult to interpret. As in the preceding tests, in which no soil-improving crops were used, tobacco behaves more like potatoes than corn in its response to the influence of preceding crops. Why intervening leguminous crops intensify rather than dissipate the differences in effects of wheat, oats, and rye as preceding crops is not clear. Judged by the older tests previously discussed, the initial increases in yields of tobacco resulting from the addition of legumes to the rotation may be expected to be followed by declining yields. The depressing effect of vetch on the growth of tobacco, in fact, is plainly indicated in the crop of 1924. One of the surprising results is the inability of tobacco and potatoes to effectively utilize the nitrogen supplied by soy beans. Corn apparently appropriates the nitrogen from the soy beans almost, if not quite, as readily as that from other legumes.

It seems possible that the unfavorable effect of grass on the hoed crops is due in part to some factor other than those concerned in the preceding crop effects, for this effect extends to all of the three hoed crops. Each of these crops following grass has shown a yellowish-green color suggestive of nitrogen hunger, and it is possible that this is one of the important factors involved. Bizzell (*2*) has investigated this phase of the effect of crops on those following in the rotation. It has been observed, also, that liming partially overcomes the unfavorable effect of grass. Interference with the nitrogen supply, however, is not the only way in which grass may depress the growth of tobacco. It has been the experience of growers in the Connecticut Valley that tobacco frequently makes very poor growth for the first year or two following timothy sod, even though heavy applications of nitrogenous fertilizers are made. The part played by the grass here may be similar to that of the legumes.

It remains to consider the effects of introducing the soiling crops into the rotation on the small grains following after the hoed crops. The data are summarized in Table XIII.

TABLE XIII.—*Summary of results with small grains on Fields IV and V for the years 1917–1923, inclusive, showing the comparative effects of tobacco, potatoes, and corn as preceding crops on the yields of wheat, oats, and rye, when soiling crops are included in the rotation; also the residual effects of the soiling crops on the yields of wheat, oats, and rye*

| Soiling crop grown | Yield of wheat | | | | Yield of oats | | | | Yield of rye | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | After tobacco | After potatoes | After corn | Average | After tobacco | After potatoes | After corn | Average | After tobacco | After potatoes | After corn | Average |
| | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* | *Bush.* |
| Vetch | 17.2 | 18.1 | 13.2 | 16.2 | 44.2 | 54.5 | 25.5 | 41.4 | 23.9 | 28.3 | 14.7 | 22.3 |
| Crimson clover | 16.9 | 18.6 | 13.2 | 16.2 | 42.6 | 53.4 | 23.3 | 39.8 | 18.5 | 25.4 | 12.1 | 18.7 |
| Fallow | 13.1 | 17.5 | 10.3 | 13.6 | 27.2 | 37.9 | 15.1 | 26.7 | 15.8 | 21.7 | 12.3 | 16.6 |
| Cowpeas | 15.5 | 21.0 | 13.0 | 16.5 | 42.6 | 48.2 | 18.6 | 36.5 | 18.2 | 26.1 | 15.6 | 20.0 |
| Soy beans | 17.0 | 22.1 | 10.5 | 16.5 | 37.8 | 42.9 | 19.4 | 33.4 | 18.3 | 22.4 | 14.1 | 18.3 |
| Grass | 13.3 | 18.3 | 9.1 | 13.6 | 27.6 | 32.2 | 14.8 | 25.2 | 17.3 | 21.9 | 13.3 | 17.5 |
| Average | 15.5 | 19.3 | 11.6 | 15.4 | 37.0 | 45.0 | 19.5 | 33.8 | 18.7 | 24.3 | 13.7 | 18.9 |

| Soiling crop grown | Yield of wheat straw | | | | Yield of oats straw | | | | Yield of rye straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* |
| Vetch | 1,972 | 2,358 | 1,572 | 1,967 | 2,332 | 3,237 | 1,196 | 2,255 | 2,980 | 3,770 | 1,866 | 2,872 |
| Crimson clover | 2,019 | 2,485 | 1,404 | 1,970 | 1,886 | 2,694 | 829 | 1,803 | 2,187 | 3,382 | 1,311 | 2,293 |
| Fallow | 1,306 | 1,938 | 966 | 1,403 | 1,126 | 1,631 | 632 | 1,130 | 1,806 | 2,934 | 1,335 | 2,025 |
| Cowpeas | 1,809 | 2,714 | 1,329 | 1,951 | 1,800 | 2,083 | 780 | 1,554 | 2,437 | 3,627 | 1,876 | 2,647 |
| Soy beans | 1,873 | 2,777 | 1,133 | 1,927 | 1,766 | 1,806 | 690 | 1,421 | 2,277 | 3,138 | 1,653 | 2,356 |
| Grass | 1,399 | 2,285 | 837 | 1,508 | 1,103 | 1,489 | 647 | 1,080 | 2,047 | 2,938 | 1,543 | 2,176 |
| Average | 1,730 | 2,426 | 1,207 | 1,788 | 1,660 | 2,157 | 796 | 1,541 | 2,289 | 3,298 | 1,597 | 2,395 |

Comparing the results collectively with those in the rotations of hoed crops and small grains without soiling crops (Tables XIII and VIII), it is apparent that, qualitatively, the relative effects of tobacco, potatoes, and corn remain the same. On the other hand, there are some very striking quantitative differences in the two series. The general effect of the legumes has been to intensify the differences in effects of the three hoed crops on the yields of succeeding crops of small grains. It is an interesting fact that in both series of tests the comparative average effects of tobacco, potatoes, and corn are practically the same for the straw as for the grain of the wheat, oats, and rye. In other words, these crop effects apply to the growth of the plant as a whole rather than that of particular parts and in this way differ somewhat from the effects produced by the fertilizer treatments (Table VIII). The large increases in yields of small grains resulting from the residual effects of the legumes emphasize the fact that the latter have furnished an ample potential supply of nitrogen for the hoed crops, even in the case of soy beans.

The yields of wheat on the control plots indicate that on Field IV the soil of the corn section is somewhat more productive than that of the tobacco and potato sections, while on Field V the reverse appears to be true. Making due allowance for these soil irregularities, it is apparent that corn, in comparison with tobacco and potatoes, depresses the yields of all the small grains (pl. 6). The effect of tobacco on oats resembles that of potatoes rather than that of corn, as in the previous tests, while the yields of wheat and rye after tobacco are about midway between the yields after potatoes and after corn. An outstanding feature is the large increase in the yields of oats after tobacco and potatoes resulting from the residual effects of the legumes. In some years these yields have exceeded 80 bushels per acre. Wheat and rye are less responsive to the residual effects of the legumes. The simplest assumption concerning the cause of the marked residual action of the legumes on the small grains after tobacco and potatoes is that the latter crops were unable to make use of the nitrogen supplied by the legumes, thus leaving in the soil considerable supplies for the small grains. Corn, on the other hand, probably has appropriated most of the nitrogen, leaving but little for the wheat, oats, and rye. There is an interesting question, however, as to why oats after tobacco and potatoes are benefited to a far greater extent than are wheat and rye through the residual action of the legumes. It seems that some factor other than the nitrogen supply has limited the growth of the wheat and rye. The comparative effects of tobacco, potatoes, and corn on the yields of the small grains as influenced by the soiling crops are shown graphically in Figures 15, 16, and 17.

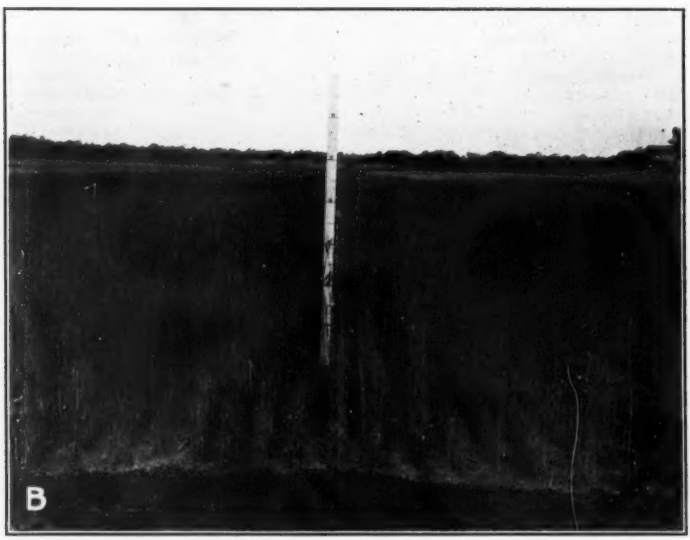
As to the individual soiling crops, it appears that all the legumes have been about equally effective as a whole, although in some cases oats and rye have shown larger gains in yield from the winter legumes than from the summer legumes. It is of considerable interest to note that the depressing action of grass on growth of crops immediately following, so plainly shown by tobacco and potatoes and to a lesser extent by corn, does not extend to the succeeding crops of small grains, the yields on the grass plots checking satisfactorily with those on the fallow plots. This indicates that the unfavorable effects of the grass are only temporary.

## RELATIVE EFFECTS OF TOPS AND ROOTS OF CERTAIN PLANTS ON GROWTH OF TOBACCO

The results of the preceding field tests show that, as compared with such crop plants as corn, tobacco is quite sensitive to the effects of preceding crops. These crop effects are not due entirely to the action of the preceding crops on the supply of available plant nutrients in the soil. In some cases unfavorable effects are noted from preceding crops, even when their aboveground portions are removed from the field in harvesting. It seemed of interest, therefore, to compare the effects of the tops and roots of some plants on the growth of tobacco, and some preliminary pot and field tests have been made along these lines.

Glazed 6 and 2 gallon earthen jars were used for the pot tests. Soil from the experimental field which had not been previously cropped was used, and no fertilizer was added. With the larger jars 8,330 grams of soil, and for the smaller jars 2,500 grams were used. The moisture content was maintained at approximately optimum. In the larger pots 200 grams of the plant material were incorporated in the soil, and 66 grams in the smaller pots. The tobacco plants were set out on December 26, and harvested March 6. Detailed observations were made on green weights of tops and roots of the

A.—Wheat in rotation with potatoes and crimson clover on Field V, 1922. The growth is far better than in the rotation with corn and crimson clover. (See B)




B.—Wheat in rotation with corn and crimson clover on Field V, 1922. After corn the growth of small grains is much less influenced by the residual action of solling crops than when following after potatoes or tobacco

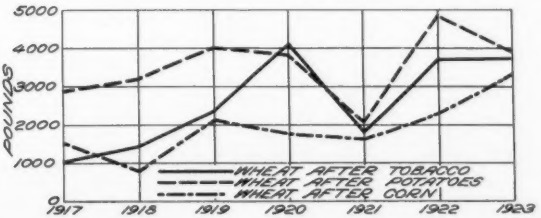



FIG. 15.—Effects of tobacco, potatoes, and corn on yield of wheat when soiling crops are in the rotation. In the early years of the test potatoes showed a markedly beneficial effect as compared with tobacco, but in subsequent years the difference between the effects of tobacco and potatoes have been much smaller. Corn has shown a depressing action throughout the test

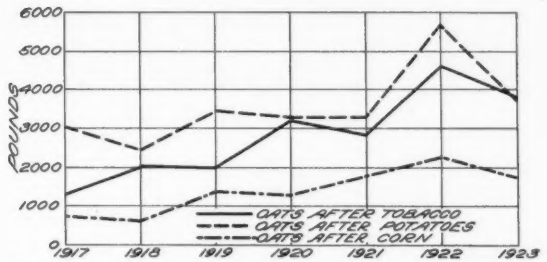



FIG. 16.—Effects of tobacco, potatoes, and corn on yield of oats when soiling crops are in the rotation. The outstanding feature is the marked upward trend in yield of oats after tobacco, the yield in later years of the test almost equaling that after potatoes; the progressive gain after corn from the residual effects of the soiling crops is comparatively small

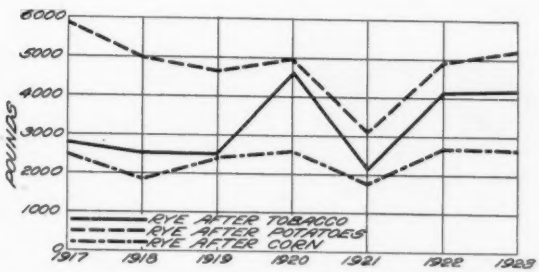
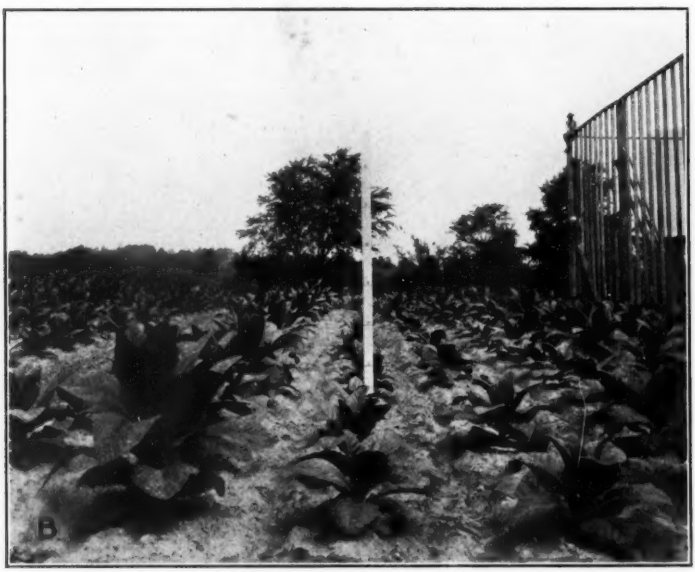



FIG. 17.—Effects of tobacco, potatoes, and corn on yield of rye when soiling crops are in the rotation. In comparison with corn, potatoes have shown a strikingly beneficial effect on the rye. This was true also of the potatoes in comparison with tobacco in the early years of the test, while, more recently, the growth of rye after tobacco has approached more nearly that after potatoes

A.—Comparative effects of roots and tops of potatoes on growth of tobacco plants in pots. At right, effect of potato roots placed in the soil and, at left, effect of tops of potatoes. Pot in center is a control. It will be seen that the roots seem to depress growth, while the tops apparently promote growth of tobacco. Similar results were obtained with tops and roots of vetch




B —Comparative effects of tops and roots of hairy vetch on growth of tobacco in the field. Row in center is a control to which no vetch material was added. Row to left of center received tops of fresh vetch plants, and row to right of center received roots of vetch plants applied to the soil about seven weeks before transplanting the tobacco. A beneficial action is shown by the tops but none by the roots

tobacco plants, the size of the leaves, and quantity of water transpired, but these data need not be given here. As shown in Plate 7, A, the roots of potatoes retarded the growth of tobacco, while the tops somewhat increased the rate of growth. The same results were obtained with the roots and tops of hairy vetch. Corn roots retarded growth somewhat, while no harmful effect was observed with tobacco roots. The tops and roots of vetch used in the tests were from fresh plants while the other plant material was from the growth of the preceding summer.

A field test was made on the experimental farm with fresh tops and roots of hairy vetch and crimson clover. The land used had been cropped to tobacco for several years. The plant material was applied in the row at the rate of two tons green weight per acre. The material was applied May 7, and the tobacco was set June 26. No fertilizer was used. Alternate rows were used as controls. With both the vetch and clover the tops gave increased growth, while the vetch roots retarded growth and the clover roots seemed to have no decided effect (pl. 7, B). These preliminary tests seem to indicate that the injurious effects of certain crops on tobacco are due to the roots. If this be true, it would seem to present new problems in the matter of supplying desirable forms of organic matter to the soil and at the same time of insuring adequate aeration.

## CONCLUSIONS

Fairly extensive field experiments have been in progress in southern Maryland for several years to determine whether legumes and other soil-improving crops, combined with commercial fertilizers, can be used successfully in applying intensive methods to tobacco culture; and to study the comparative effects of various crops on those which follow in rotation, with special reference to tobacco. The soil used is the fine sandy loam type of the Collington series. The results to date do not support the view which has been often advanced that tobacco is especially injurious to the general productiveness of the soil. On the other hand, it appears that the tobacco plant is particularly sensitive to the effects of preceding crops, and attempts to apply intensive methods, as turning under soil-improving crops freely or applying large quantities of manures and fertilizers, are likely to fail. The growth of the tobacco plant may be seriously retarded as a result of the effects of preceding crops of tobacco itself or of various other plants. Under the intensive methods in question, reduced yields of tobacco do not involve a reduction in the general productiveness of the soil.

In special cropping tests with tobacco, moderately fertilized, use of hairy vetch, crimson clover, and rye as soiling crops in continuous tobacco culture has given rather large increases in yield of tobacco during the first few years of the tests. In later years, however, the yields of tobacco have been very variable, depending largely on weather conditions. In dry years the yield has been rather good, while in wet years it has been less than that of the control plot, and the quality of the leaf has been poor. There is a tendency toward very uneven growth, but both large and small plants contain a high percentage of nitrogen. Much the same results have been obtained with crimson clover and cowpeas used as soiling crops for tobacco in a two-year rotation with wheat. For the period of the tests the general trend in yield of tobacco since the initial increase from the soiling crops has been downward. In a three-year rotation of tobacco, wheat, and red clover, both the yield and the quality of the tobacco have been more stable and have averaged considerably higher than those of the control plot. It is possible, however, that these results are due largely to the fact that the land is substantially in a resting condition for the greater portion of the rotation period rather than to any specifically favorable influence of the red clover. In any event, it is a striking fact that none of the cropping systems tested have given results with tobacco equal to those obtained on rested land, that is, land occupied for a period of years by adventitious vegetation. Leaving out of account instances of infestation with Thielavia root-rot, at the present time the only system of soil management known to be effective in restoring to normal the yield of tobacco which has declined under intensive methods is the simple expedient of allowing the soil to remain idle for a period of years. It appears that while limited use of soil-improving crops under favorable circumstances may give profitable returns with tobacco, conditions may easily arise where their use would be positively detrimental. In the present series of tests, use of soil-improving crops combined with liming but without use of commercial fertilizer has soon resulted in practical failure of the tobacco crop.

The comparative effects of the three crops, tobacco, potatoes, and corn, on succeeding crops have been studied by growing each of these three crops in (1) continuous culture and in alternation with the other two; (2) rotation with each of the small grain crops, wheat, oats, and rye; and (3) rotation with each of the three small grain crops, including hairy vetch, crimson clover, cowpeas, soy beans, and a mixture of grasses as soiling crops in the rotations. Except where the soiling crops were used, four different fertilizer treatments have been used in each system of cropping. Although the potato crop removes from the soil only small quantities of plant nutrients, while corn removes much larger quantities, tobacco for the most part has resembled potatoes rather than corn in its effects on succeeding crops. In continuous culture, tobacco has shown a tendency to decline in yield, but more recently the growth after corn has been poorer than in continuous culture. Potatoes have given best yields after tobacco and poorest yields after corn. The corn crop has not been greatly affected by preceding crops. In comparison with tobacco and potatoes, the corn crop has decidedly reduced the yields of succeeding crops of wheat and oats, and, to a lesser extent, rye. In earlier years, the growth of small grains after potatoes was considerably better than after tobacco, but this difference has not been fully maintained. Addition of legumes to the cropping system has intensified rather than overcome the differences in effects of tobacco, potatoes, and corn on the small grains. The effects of vetch crimson clover, and cowpeas on tobacco have been the same as noted in the previous paragraph. Soy beans have given especially poor results with tobacco and potatoes. Grass as a soiling crop has markedly reduced the yield of tobacco and potatoes, and to a lesser extent, the yield of corn. Neither tobacco nor potatoes have been able to effectively utilize the nitrogen of the legumes. Corn and the small grains, on the other hand, have been greatly benefited by the legumes, readily taking advantage of the nitrogen furnished by them.

The results of these cropping tests furnish a group of crop effects which are not wholly explainable either on the basis of the plant-food theory or of parasitic disease. These crop effects are of a transitory character, in so far as they are toxic or injurious, and are markedly influenced by the character of the soil and the weather conditions. They are also influenced to some extent by fertilizers and lime. Preliminary field and pot tests with tobacco indicate that the injurious effects of preceding crop plants come mostly from the roots rather than the tops of these plants. If these results are confirmed, they would seem to suggest new problems in the matter of most effectively supplying the soil with organic matter.

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# SOME EFFECTS OF SEASONAL CONDITIONS UPON THE CHEMICAL COMPOSITION OF AMERICAN GRAPE JUICES [1]

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## PURPOSE OF THE WORK

The studies here reported were undertaken for the purpose of obtaining information as to the effects of variation in climatic conditions over a series of years upon the chemical composition of some of the more important varieties of American grapes, when grown together under known and controlled conditions of cultivation, pruning, and fertilization upon a soil of known physical character and chemical composition.

While a considerable number of chemical analyses, covering most of the older and more widely known commercial varieties of grapes, may be found in the literature, few of them are accompanied by any data on the cultural treatment received by the vines or the climatic conditions under which the analytical material was grown. Before the results of chemical analyses can be employed to formulate the definition in chemical terms of desirable dessert quality or to guide the breeder in selection of more desirable varieties, the extent to which annual variations in environmental conditions affect chemical composition must be definitely known.

No systematic attempt, so far as is known to the writer, has ever been made to secure uniformity in all cultural treatments over a series of years for a large number of varieties growing side by side and to determine the nature and extent of the fluctuations in chemical composition of the fruit resulting from the variations in environmental conditions encountered during the production of a number of crops. The writer knows of no data in the literature indicating the extent to which such seasonal conditions as drought, excessive rainfall, minimum sunshine during the growing period, or other departures from normal in environmental conditions affect the chemical composition of the crop.

Investigations of methods for the more effective utilization of some of the varieties of grapes grown throughout the Central and Eastern States were undertaken by the Office of Horticultural Investigations of the Bureau of Plant Industry, United States Department of Agriculture, in 1918. These investigations were made on account of the fact that there is sometimes a considerable surplus of varieties grown for dessert use and the products from varieties formerly grown extensively for wine making have not yet found a profitable place in legitimate markets. One outlet for a considerable part of the grape surplus is in the manufacture of unfermented grape juice, where there is a demand in excess of the supply. To satisfactorily meet this demand, the juices must not only be acceptable in beverage quality but must be standardized and uniform in character. Relatively few grapes produce juices having such a balance between sugar, acid, and astringent constituents as to be wholly satisfactory for making unfermented beverages; no other grape has seriously rivaled the Concord, which possesses such a balance, as a source of juice. Successful additions to the beverage-juice supply are scarcely to be looked for through the making of single-variety juices, but the blending of juices of two or more varieties offers wide possibilities for the making of products of any desired character.

Before such work can proceed in any other than purely haphazard, cut-and-try fashion, accurate information as to the chemical composition of the various new materials must be in hand. In order not to be misleading, such information must furnish an idea as to the extent and nature of the variations in chemical composition which are likely to occur in the juices of given varieties from year to year as a result of varying seasonal conditions. Such

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a background of information as to chemical composition would indicate also the other uses to which the various varieties are adapted. This paper presents the results of an attempt to secure such a background.

## THE EXPERIMENT VINEYARD

### Location

The Office of Horticultural Investigations of the Bureau of Plant Industry established an experiment vineyard of selected varieties at Vineland, N. J., in 1908, which was the source of the material used in the work.

Vineland is located near the northern boundary of Cumberland County, which borders upon Delaware Bay at the extreme southern tip of New Jersey. The experiment vineyard is located about 1¼ miles southeast of the town limits. The Millville area, within which the vineyard lies, has been described in detail by the Bureau of Soils, United States Department of Agriculture, (*20*)[2] and the chemistry of the soils of the area has been studied by the New Jersey Agricultural Experiment Station (*15*). The description of the locality given here is summarized from the publications just referred to.

The area is on the Coastal Plain, and is characterized as a whole by its flatness and lack of relief. The region adjacent to Vineland has a number of low, flattened ridges rising from 10 to 30 feet above the general surface, which is 109 feet above sea level at Vineland. The soils of the whole area are of comparatively recent and largely marine origin, the Cohansey sand formation overlying most of the area, and consist for the most part of sand and gravel with a small percentage of clay. In the locality in which Vineland is situated the soil is classified as Sassafras gravelly sandy loam. The surface soil is a light brown loamy sand to sandy loam, 6 to 8 inches in depth, beneath which is a yellow or yellowish-red sandy loam 4 to 8 inches in depth. The subsoil is a dull red or reddish-yellow sandy clay with some grave and coarse sand, which are in greater proportion with greater depth. White and yellow quartz gravel one-eighth to three-fourths inch in diameter occur in varying proportions throughout both surface soil and subsoil. While somewhat deficient in plant food and requiring addition of lime, as indicated by the analyses in Tables I and II, the soils have good drainage, become warm early in the spring, and are easy to cultivate. About 50 per cent of the Sassafras gravelly sandy loam in the area has been cleared and is devoted to the cultivation of vegetables and fruits. Sweet potatoes, peppers, tomatoes, sweet corn, strawberries, raspberries, Lima beans, and peas are the principal truck crops. The area immediately adjacent to Vineland has become a rather intensive peach-growing district, and the planting of apples is increasing. The tree fruits have to a considerable extent displaced grapes, which were formerly much grown but which gradually became unprofitable on account of improper management. Where effective methods of controlling disease and maintaining soil fertility have been adopted the vineyards continue to yield profitable crops.

TABLE I.—*Composition of Sassafras loamy sand and Sassafras gravelly sandy loam, Vineland, N. J.*

| Soil type and location | Depth sampled | Percentages of— | | | | | |
|---|---|---|---|---|---|---|---|
| | | Nitrogen (N) | Phosphoric acid ($P_2O_5$) | Potash ($K_2O$) | Lime (CaO) | Magnesia (MgO) | Carbon (C) |
| Sassafras loamy sand 1 mile east of Vineland, at Spring Road and Landis Avenue | *Inches* 0 to 9 | 0.050 | 0.083 | 0.373 | ..... | ..... | 0.750 |
| Subsoil, same | 9 to 36 | .023 | .043 | .947 | ..... | ..... | .215 |
| Sassafras gravelly sandy loam, near Vineland | 0 to 8 | .089 | .083 | .685 | 0.315 | 0.290 | 1.589 |
| Subsoil, same | 8 to 34 | .028 | .035 | .685 | .210 | .319 | .309 |
| Sassafras loamy sand at Norma, 3½ west of Vineland | 0 to 10 | .053 | .077 | .338 | .105 | .152 | .764 |
| Subsoil, same | 10 to 36 | .021 | .034 | .382 | .203 | .232 | .089 |

[2] Reference is made by number (italic) to "Literature cited," p. 1175.

TABLE II.—*Pounds of plant food per acre in upper 6⅔ inches (approximately 2,000,000 pounds of soil) in Vineland, N. J. soils*

| Soil type and location | Depth sampled | Nitrogen (N) | Phosphoric acid ($P_2O_5$) | Potash ($K_2O$) | Lime (CaO) | Magnesia (MgO) | Carbon (C) | Lime needed per 2,000,000 pounds of soil |
|---|---|---|---|---|---|---|---|---|
| Sassafras loamy sand 1 mile east of Vineland, at Spring Road and Landis Avenue | *Inches* 0 to 9 | 1,000 | 1,660 | 7,460 | ..... | ..... | 15,000 | 800 |
| Subsoil, same | 9 to 36 | 460 | 860 | 18,940 | ..... | ..... | 4,300 | ..... |
| Sassafras gravelly sandy loam, near Vineland | 0 to 8 | 1,780 | 1,660 | 13,700 | 6,300 | 5,800 | 31,780 | 3,200 |
| Subsoil, same | 8 to 34 | 560 | 700 | 13,700 | 4,200 | 6,380 | 6,180 | ..... |
| Sassafras loamy sand at Norma, 3½ miles west of Vineland | 0 to 10 | 1,060 | 1,540 | 6,760 | 2,100 | 3,040 | 15,280 | 2,000 |
| Subsoil, same | 10 to 36 | 420 | 680 | 7,640 | 4,060 | 4,640 | 1,780 | ..... |

Data for Tables I and II taken from Blair, A. W., and McLean, H. C. (*15*).

The average mean winter temperature at Vineland is 33°, for spring 51.1°, for summer 73.9°, for autumn 55.4°, the mean for the year being 53.3°. The mean spring and summer temperatures are higher, the mean fall and winter temperatures lower than those at coast points such as Atlantic City and Cape May city, while the maximum and minimum temperatures show a somewhat wider range than is the case nearer the ocean. The winters are much milder than those of northern New Jersey but are accompanied by high humidity, which often renders the cold very penetrating. There is usually very little snow, and it seldom remains long on the ground. The maximum temperatures for the year usually occur in July at Vineland, and are frequently accompanied by high humidity which makes them quite oppressive. July and August are the months of greatest rainfall, the total annual precipitation for the 50-year period averaging 46.59 inches. The growing season is considerably shorter than at coast points, averaging 185 days in length. The average date of the last spring frost is April 18; that of the first fall frost October 20.

## PLAN AND HISTORY

The experiment vineyard from which material for this investigation was obtained was established by the Bureau of Plant Industry in 1908, when a block of 10 acres was planted on the property of the Vineland Grape Juice Co. The experiments for which the planting was originally made were continued for 11 years. They included a study to determine the best varieties for the region, a study to determine the best methods of pruning and training for the varieties under trial, and tests of cover crops, clean culture, fertilizers, and spray mixtures. At the end of 1919 these experiments were terminated and the care of the vineyard was continued by the Vineland Training School for the Feebleminded, which had acquired the property. In 1920 the tract was purchased by Frank C. Bray.[3] The varietal collection was kept intact and the same methods of pruning and spraying employed prior to 1919 were continued, while the general methods of fertilization, cover cropping, and cultivation employed were those in use in the best commercial vineyards of the region. At the time the collection of material for analyses was begun in 1919 the vines were, for the most part, 11 years old, the principal planting having been made in 1908, with a few minor additions in 1909 and 1910. They had received the best of care and had been in excellent condition up to the year 1917. A very severe hailstorm on June 11, 1916, did considerable damage to vines and fruit. A rather serious attack of rootworm (*Phidia viticida*) in the year 1917 necessitated vigorous control measures during the following season and resulted in the death of a number of vines, while a few of the less vigorous varieties required several years to recover from the attack. On August 14, 1918, a very severe wind and rain storm, at a time when the ground was thoroughly saturated, did

[3] The writer desires to express his obligations to the authorities of the Vineland Training School and to Mr. Bray for the opportunity to obtain samples of fruit for use in this investigation, and for the facilities afforded him for the work.

considerable damage by tearing down trellises and breaking vines. With the exception of about a dozen varieties which showed more or less injury from these causes, the vineyard was in excellent condition when the collection of samples was begun in 1919.

The varietal plantings from which the fruit used in the studies here reported was taken occupy a rectangular block of 10 acres, situated on the crown of a low, flattened ridge which runs northeast and southwest. The plot is not perfectly level but is on gentle southern and northern slopes, with the western edge sloping slightly toward the northwest. The difference in elevation is not more than 5 or 6 feet, except at the extreme northwestern corner. The elevation above sea level at the center of the plot is 118.5 feet. The rows of vines run northeast to southwest.

The total number of varieties in the vineyard is 67. The main planting consists of 144 vines each of the following 27 varieties: Brilliant, Campbell Early, Catawba, Concord, Cynthiana, Delaware, Diana, Dutchess, Elvira, Goethe, Herbemont, Herbert, Ives, Lenoir, Lindley, Montefiore, Moore Early, Niagara, Noah, Norton, Pocklington, Salem, Vergennes, Winchell, Wilder, Woodruff, and Worden; with 72 vines each of the 5 varieties: Clevener, Diogenes, Franklin, King Philip, and Martha. As each row in the vineyard contained 72 vines, each variety of the group of 27 varieties first named occupied two full rows, and each variety of the last-named group occupied one row. In order to avoid any differences due to the different conditions on the north and south slopes, the planting of each variety was distributed equally between north and south sides of the vineyard.

In addition to the principal plantings, a plot lying on the eastern side of the main block had been planted to 10 vines each of the following 31 varieties: Agawam, Barry, Berckmans, Brighton, Canada, Centennial, Colerain, Champion, Diamond, Eaton, Early Daisy, Early Victor, Eumelan, Gaertner, Isabella, Iona, Jefferson, Hartford, Lampasas, Lucile, Lady, Massasoit, Merrimac, Missouri Riesling, Nectar, Perkins, Rommel, Ulster, and three varieties designated in the records as "Studley No. 2," "Seibel Hybrid No. 1," and "Seibel Hybrid No. 2." In addition, there were in the original plantings four to six vines each of Beta, Dakota, "Dutchess seedling," Downing, Geyer, Husmann, Rebecca, "Viticultural No. 3405," and "Viticultural No. 3506." Of these, only "Dutchess seedling" and Rebecca bore fruit, and these only in 1922 and 1923. At the time this work was begun in 1918 no vines of Beta remained living, and the vines of Downing, Geyer, and Husmann never bore more than an occasional cluster of fruit. The varieties designated as "Viticultural No. 3405" and "Viticultural No. 3406" bore occasional clusters of small, worthless fruit and there was an entire failure to mature. The block of vines designated as "Studley No. 2" contained two varieties neither of which was Studley No. 2 and neither of which has been positively identified. Consequently none of these varieties appears in the reports of analyses.

In order to test various types and amounts of fertilizer and different methods of pruning and training, the vineyard had been divided, at the time of planting, at right angles to the rows of vines, into 12 plots each 6 vines in width. These 6 vines were pruned and trained by different methods, the first by low renewal, the second by four-arm renewal, the third by high renewal, the fourth by the fan system, and the fifth and sixth by the Munson system. A thirteenth plot contained all the small plantings of 10 vines of a variety with a few vines each of miscellaneous varieties forming a border. Each of the larger plantings extended across the other 12 plots, hence had equal numbers of vines trained by each of the systems except the Munson, which had twice as many as any of the others.

The effects of injury from the attack by rootworm in 1917 and 1918 were evident in a number of varieties for several years in the form of slow growth, deficient vigor, and light yields. The varieties which were obviously not normal in condition in 1918 were Brilliant, Campbell Early, Catawba, Cynthiana, Colerain, Early Victor, Iona, Jefferson, Lady, Lenoir, Nectar, Norton, Pocklington, and Woodruff. By careful handling and restricting the crop they were allowed to carry, Catawba, Cynthiana, Brilliant, Nectar, Colerain, Pocklington, Norton, and Jefferson were brought back to normal vigor and fruitfulness in 1919. A considerable number of vines of Campbell Early and Iona had died or been cut back to the ground so that only a part of the original vines were bearing; those not cut back made only partial recovery, but the new growth from old stumps was normal. Lady, Early Victor, Nectar, and Woodruff remained below normal in vigor of growth and size of crop throughout the experiments, Woodruff

especially ripening very irregularly, dropping its foliage badly, and failing to color a portion of its fruit. Lenoir bore rather light crops in 1919 and 1920, but had fully recovered by 1921.

In view of these conditions, the varieties may be divided into two groups, one consisting of 49 varieties which were normally vigorous in vine and fruit and which bore annual crops of fair size, ripening their fruit uniformly. (The data for these varieties are presented in Table III.) The other 16 varieties include all those which for any reason failed to fruit annually and in fair amount through the period of the experiment. The reasons for the failures were various, but some of them were poor adaptation to the environment, susceptibility to insect or fungus injury, to scorching of foliage by spray, partial sterility, or shy bearing. Analyses of these, with summaries of the field notes as to their behavior, are given in Table IV. All comparative discussion is based upon the results with the 49 normal annual-bearing varieties of Table III.

## BOTANICAL RELATIONSHIPS OF THE VARIETIES

Some of the varieties used were purebred and some were hybrids. While horticulturists are by no means unanimously agreed as to the parentage of several of the varieties, the following table is believed to represent the majority of opinion. The statements of Hedrick (*29*, *30*) have been followed in the main, supplemented by those of Munson (*49*) and the Bushberg catalogue (*16*).

1. *Purebred Vitis labrusca:* [4]
   - Champion.
   - Colerain (white seedling of Concord).
   - Concord.
   - Early Daisy (seedling of Hartford).
   - Eaton (seedling of Concord).
   - Hartford.
   - Ives.[5]
   - Lady (seedling of Concord).
   - Lucile (seedling of Wyoming).
   - Moore Early (seedling of Concord).
   - Pocklington (seedling of Concord).
   - Vergennes.
   - Worden (seedling of Concord).
2. *Labrusca-vinifera hybrids:*
   - Agawam (Labrusca × Black Hamburg).
   - Barry (Labrusca × Black Hamburg).
   - Brighton (Concord × Diana Hamburg).
   - Campbell Early (Moore Early × Labrusca × Vinifera).
   - Catawba.
   - Diamond (Concord × Iona).
   - Diana (seedling of Catawba).
   - Gaertner (Labrusca × White Chasselas).
   - Goethe (Labrusca × Black Hamburg).
   - Herbert (Labrusca × Black Hamburg).
   - Iona (seedling of Diana.[6])
   - Isabella.
   - Jefferson (Concord × Iona).
   - Lindley (Labrusca × White Chasselas).
   - Martha (seedling of Concord).
   - Massasoit (Labrusca × Black Hamburg).
   - Merrimac (Labrusca × Black Hamburg).
   - Niagara (Concord × Cassady).
   - Perkins.
   - Rebecca.
   - Salem (Labrusca × Black Hamburg).
   - Ulster.
   - Wilder (Labrusca × Black Hamburg).
   - Woodruff (Concord × Catawba).
3. *Labrusca-aestivalis* hybrids:
   - Cynthiana.[7]
   - Norton.[7]
4. *Labrusca-aestivalis-vinifera* hybrids:
   - Centennial (Labrusca × Eumelan seedling).
   - Eumelan.[8]
   - Winchell.
5. *Labrusca-bourquiniana* hybrids:
   - Early Victor (Delaware × Hartford) (?)
6. *Labrusca-vinifera-bourquiniana* hybrids:
   - Brilliant (Lindley × Delaware).
   - Delaware.
   - Dutchess (Concord seedling × Walter or Delaware).
7. *Labrusca-vulpina* hybrids:
   - Clevener.
   - Clinton.
   - Dakota (Concord × vulpina ?).
   - Diogenes.
   - Elvira (seedling of Taylor).
   - Franklin.
   - Missouri Riesling (probably seedling of Taylor).
   - Montefiore (Taylor × Ives).
   - Noah (seedling of Taylor).
8. *Labrusca-vulpina-vinifera* hybrids:
   - Canada (Clinton × Vinifera).
   - King Philip.
   - Rommel (Elvira × Triumph).
9. *Labrusca-vulpina-bourquiniana* hybrids:
   - Beckmans (Delaware × Clinton).
10. *Purebred Vitis bourquiniana:*
    - Herbemont.
    - Lenoir.

This collection of grapes is characterized by the absence of purebred varieties of species other than Vitis labrusca and bourquiniana and by the presence of a strain of labrusca in all the hybrids. In consequence the results do not adequately represent the range of varieties which are at present available to growers through the work of breeders who have employed other species as parents. These varieties include practically all the older and more widely known varieties which were grown in the Central and Eastern States 15 years ago, hence give information in regard to nearly all varieties which have attained commercial importance in that area.

[4] Tukey (*59*) is inclined to the belief that Vitis vinifera blood may in reality be much more generally present in American varieties than has hitherto been considered to be the case. He states some evidence that Concord and its seedlings have Vinifera in their ancestry, and regards Vergennes as undoubtedly containing a strain of Vinifera.

[5] Ives is considered by Munson and the authors of the Bushberg catalogue as pure Labrusca, while Hedrick considers it a Labrusca-aestivalis hybrid.

[6] This is Hedrick's statement (*30*, *p. 390*), the Bushberg catalogue (*16*, *p. 111*) states that Iona is a seedling of Catawba.

[7] The Bushberg catalogue lists both Cynthiana and Norton as pure Aestivalis, to which Munson agrees.

[8] The Bushberg catalogue (*16*, *p. 99*), calls Eumelan an Aestivalis, remarking that it was designated as Labrusca in the first edition by a typographical error and that the error has been widely copied.

## THE METHODS EMPLOYED

### Collection and Preparation of Samples

In any work of this character the value of the results hinges wholly upon the securing of samples for analysis which are truly representative of the crop as a whole. The method of collecting samples here employed was purposely chosen to eliminate the errors inherent in the selection of small samples of fruit which have been pointed out by Denny (*19*) and by Haynes and Judd (*28*) and was made easier by the fact that considerable quantities of the juice of each variety were desired for other experimental purposes. In the case of the varieties of which there were only 10 vines, the entire crop of the 10 vines was harvested, thus making a sample of 30 to 75 pounds. In the case of those varieties of which there were 72 or 144 vines each, the entire crop could not be used, and the owners usually picked the fruit of a given variety for sale about 6 to 10 days before it was judged to be fully ripe. Consequently the entire planting of a variety was examined and a number of vines standing consecutively in the row and including equal numbers of vines trained by each of the methods of pruning employed and ranging from 15 to 40 in number were reserved for use in this work and the picking was postponed until the crop was fully ripe. The block of vines so chosen was thus as truly representative of the whole planting of the variety, in appearance and condition of vines and size of crop, as it could be made, and the entire crop from the block was harvested together, the pickers being instructed to leave no fruit on the vines. The samples so obtained ranged from 50 to 300 pounds in weight, usually averaging about 150 pounds. It is believed that these samples were as free from the effects of conscious or unconscious selection and as truly representative of the whole product of the vines as could be.

As rapidly as picked, the fruit was conveyed to a building near the vineyard and pressed. Unless otherwise noted, all samples were cold pressed, i. e., pressed without previous heating. A large-size hand cider press was used, the grater being adjusted so as to burst the individual grapes without crushing the seeds. Racks and cloths were substituted for the slatted device usually supplied with such presses. A sufficient number of cloths were provided to permit the washing of each cloth after it was once used and drying it before it was used again, and the press and racks were thoroughly cleaned and washed after the pressing of each variety was completed. About 50 to 65 pounds of fruit could be handled at one pressing. In order to accomplish an extraction of juice comparable with that obtained by the smaller hydraulic presses, a 6-foot lever was used and the screw was forced down as far as two strong men could turn it. After draining had stopped, the press was opened, the cakes were broken up and returned to the cloths and the pressing repeated. That the extraction of juice was comparable to that obtained in ordinary commercial practice by the use of a hydraulic press is evidenced by the yields of juice obtained, which ranged from 6.9 to 8 gallons per 100 pounds of fruit.

Juices expressed in this manner will differ appreciably in composition from those obtained by pressing small samples of fruit through muslin by hand, though some workers have assumed that such hand-pressed samples accurately represent the composition of the crop. The writer has repeatedly made analyses of samples made from the same lot of grapes, by pressing in the press here used, and by crushing the fruit, placing it in a strong cloth, and squeezing with the hands until no more juice could be expressed. In every case a less complete extraction of juice was obtained by hand pressing, as shown by the weight of the residues. Hand-pressed samples show considerably lower acid, higher sugar, and higher total solids than do those made with a press, and these differences, superposed upon the error which usually occurs in taking small samples, give analytical results materially higher for sugar and solids than the true ones.

The juice was received as it drained from the press into enamel-lined pails of a size sufficient to contain the juice from one pressing. As soon as the pressing of a variety was complete the juice was carried into the workroom and sampled. If the juice from a variety occupied only one container, it was thoroughly stirred while portions for the various determinations were pipetted into beakers. If the lot of fruit was of such size that the juice filled two or more containers, an equal amount was measured from each, after thorough stirring, into another vessel, and the samples for analysis were taken from this vessel. Thorough agitation during the taking of samples is by no means superfluous, as many juices throw down an abundant flocculent precipitate immediately after pressing.

In the first two years of the work, 1919 and 1920, the determinations made in the field were confined to acid content, specific gravity, and sugar content by the Brix scale saccharimeter. Beginning in 1921, determinations of total astringency and nontannin astringency were also made. All the determinations upon any given sample of juice were invariably completed within 30 minutes after pressing was completed. The remainder of the juice was then placed, after again stirring to secure uniformity, in quart bottles, half-gallon glass jugs, or in fruit jars of the Lightning Seal type, sealed, numbered serially for identification, and pasteurized by submerging in cold water, bringing to 80° C. for 5–15 minutes, and cooling slowly out of drafts. Analytical work upon the juices so prepared had to be postponed until the winter of 1921–22, the juices in the meantime having been stored in the original containers after shipment to Washington from Vineland. The desirability of securing additional data upon the freshly pressed juices for comparison with those subsequently to be obtained from the same juices after pasteurization became apparent as soon as the analytical work was well under way. In consequence, the preparation of samples in 1922 and 1923, in addition to samples pasteurized as in the previous years, included the preparation of duplicate samples which were preserved with bichloride of mercury, without heating, for sugar determinations. The bulk of the juice was pasteurized as in previous years.

The methods employed in the field determinations were essentially those of the Association of Official Agricultural Chemists (*10*), with the following modifications:

ACIDITY.—Twenty-five c. c. of juice was pipetted into a 400 c. c. beaker and made up to 250 c. c. with water, placed in such a position before a shuttered window that a beam of sunlight illuminated it from the side opposite the operator, and titrated with N/10 sodium hydroxide against phenolphthalein as indicator. By careful attention to the series of color changes occurring in the solution it was possible to be certain of the end point, even in the deeply colored juices, but the readings obtained upon such juices were checked by the use of phenolphthalein powder and a spot plate. While it is recognized that titration of a liquid such as grape juice against phenolphthalein gives high results through the inclusion of some gallotannic acid, as Gore (*24*) has shown, no other method capable of being used under field conditions gives more accurate or satisfactory results. Since the method has been used in practically all published determinations upon grape juices, it serves the purpose of the present work by yielding results which permit direct comparison.

SPECIFIC GRAVITY.—A precision hydrometer, reading to the third decimal place, was employed.

SUGAR CONTENT BY BRIX SCALE.—The value of data obtained by the use of an instrument intended for determinations upon relatively pure sucrose solutions when juices containing mainly or wholly reducing sugars and widely varying amount of nonsugar solids were to be tested seemed questionable at the outset, but as it was impossible to keep the analytical work abreast of the field work spindle readings were made. Alwood (*5*) has discussed the comparative accuracy of Oeschle, Balling, Baumé, specific gravity, and Brix spindles, reaching the conclusion that Brix determinations with a specially made type of spindle are sufficiently accurate for comparative purposes in work upon grape and apple juices if an average of the nonsugar solids of the different varieties is allowed in each case, notwithstanding the fact that such nonsugar solids range from 1.5 to 4 per cent in different varieties. Thompson and Whittier (*56*) take issue with this conclusion, stating that—

> methods employing specific gravity determinations (as by the use of the Brix spindle) as a basis for calculating the total sugars or even the solids, are very questionable on unknown solutions. In order to use such a method on a fruit juice, it is first necessary to accomplish an accurate analysis upon each fruit juice and even upon each variety of the same fruit before a spindle can be used with any degree of accuracy for determining the total sugars.

Brix precision hydrometers, calibrated to 0.1 per cent of sugar at 17.5° C., of the type recommended by Alwood, were used. As the temperatures at which the field readings had to be made were those of an open shed and varied from 6.5 to 32.7° during the work, it was not expected that the corrected readings would give more than approximations of the sugar content as determined by analysis. As soon as the analytical work was under way it became evident that the readings were without much value either for comparison of varieties with one another or for comparing the juices of the same variety in different years. The nonsugar solids of the varieties studied range from 0.57 to 4.5 per cent, and the amount in a given variety fluctuates very considerably from year to year. The occasional presence of varying amounts of cane sugar in grape juice

also contributes to inaccuracy in spindle readings. Consequently such readings were discontinued after 1921, and none of the figures either for Brix or specific gravity are published.

TOTAL ASTRINGENCY.—Determinations were made by the Loewenthal-Proctor method, employing 25 c. c. of juice diluted to 750 c. c. and titrated in presence of indigo-carmine with N/20 $KMnO_4$. Astringent nontannins were determined after precipitation of the tannins by gelatin-salt solution, shaking with kaolin, and filtering. The results are expressed in grams by the use of the conventional factor (1 c. c. N/20 $KMnO_4$ =0.0020785 gram tannin), although it is recognized that for astringent nontannins these figures do not express absolute values and are servicable only for purposes of comparison.

## PRESERVATION OF SAMPLES FOR ANALYSIS

In 1919, 1920, and 1921 the samples intended for analysis were duplicate quart bottles which were filled from the thoroughly stirred bulk sample, sealed, numbered, and pasteurized in the same manner as the remainder of the juice. The analytical work upon these samples had to be postponed until late in the autumn of 1921. In the meantime work upon the nature and amount of change in chemical composition produced in apple juices by pasteurization was in progress in the laboratory and the results obtained made it seem desirable to extend the study to grape juices. The fact that sucrose had been found in considerable quantity in the pasteurized juice of a number of varieties was an additional reason for securing data on unpasteurized juices. Samples of all varieties were preserved in 1922 and 1923 by the use of bichloride of mercury. Two half-pint bottles were filled with the juice, after thorough stirring to secure uniformity, 0.25 gram of powdered c. p. bichloride of mercury was added to each bottle, the bottles were vigorously shaken to bring the mercury into solution, sealed, and numbered. Two pint or quart bottles were filled with the same precautions to secure representative samples, sealed, and pasteurized to serve for analysis of the pasteurized juice, as in previous years.

## ANALYSIS OF SAMPLES OF JUICE

Analysis of the samples of 1919–1921 which had been shipped to Washington and stored at room temperature in a dark room, protected from freezing, in the laboratory, was begun late in the autumn of 1921. The samples were analyzed in the order of age, the 1919 samples being taken first, then those of 1920. By the time these analyses were completed the work was interrupted by the harvest of 1922. The sugar determinations on the 1922 samples preserved with bichloride of mercury were begun a few days after the receipt of the samples at the laboratory and were completed within three weeks, taking the samples in the order in which they had been prepared so that none of them stood longer than four weeks before being handled. Upon completing the work with these, the analysis of the pasteurized samples of 1921 and 1922 was taken up and completed prior to the 1923 harvest. On receipt of the 1923 samples at the laboratory, sugar determinations were at once made upon those preserved with bichloride of mercury, followed by analysis of the pasteurized samples of the same crop. So, the pasteurized samples of the crop of 1919 had been in storage a little more than three years when analyzed, those of 1920 about two and one-half years, those of 1921 about fifteen months, those of 1922 and 1923 five to seven months each, when the analyses were made. All samples were stored together, for the most part in the original shipping crates, in a dark room in which the temperatures ranged between 50 and 95° F. until taken out for analysis.

A question which naturally arises, namely, whether the analytical data obtained from juices pasteurized and stored for a period of three years is comparable with that from samples stored only a few months, can be definitely answered in the affirmative. The coagulation and precipitation of pectins, tannins, and other constituents which result from the heating of a juice in pasteurization continues for a limited time after the juice has cooled and been placed in storage, but comes to an end in the course of six to twelve months. Repeated analyses of samples of the juices here used, as well as the results of extensive studies of the changes induced by pasteurization in both apple and grape juices to be reported in detail in another publication, make it clear that a sterile pasteurized juice, stored in darkness and protected from freezing or overheating, attains a constant composition within a few months and will remain unchanged indefinitely under such conditions (*27*).

### Analytical Methods

The samples preserved by addition of bichloride of mercury were used for sugar determinations only. No correction was necessary for the amount of $HgCl_2$ used (0.25 gram for 250 c. c. of juice).

Reducing sugars were determined by clarification with neutral lead acetate, removing the excess lead with potassium oxalate, and employing the Munson and Walker method, titrating the cuprous oxide with N/20 $KMnO_4$ after solution in ferric ammonium sulphate. The results are expressed as invert sugar or as invert sugar in presence of sucrose accordingly as sucrose was found to be present or absent. Total sugars were determined by inversion of a portion of the clarified solution and application of the same method. Sucrose was determined by difference of the figures before and after inversion. Duplicate determinations were run in all cases and were repeated when the amounts of $KMnO_4$ required for titration of the copper differed by more than 1 per cent.

Acidity, total astringency, and astringent nontannins were determined by the same methods employed in the field determinations.

Total solids were determined upon special samples used only for that purpose. Before being opened the bottle was shaken vigorously to bring the sediment into suspension, and duplicate 10 c. c. samples were pipetted with a wide-tipped pipette into flat-bottomed 10 cm. Petri dishes. Sufficient distilled water was added to each dish to spread the liquid in a uniform film over the bottom, the dishes were brought almost to dryness on a water bath, and the drying was completed in a vacuum oven at 90° C.

## ANALYTICAL DATA

The analytical data are given in Tables III and IV.

### Discussion of the Analytical Data

Table III brings together all the analytical data for 49 varieties which fruited yearly during the 5-year period while Table IV presents similar data for 16 varieties which did not fruit regularly during this time. Some of the outstanding facts shown by the figures may be discussed somewhat in detail.

### SUGAR CONTENT

The range of variation in sugar content during the 5-year period shows large differences among the varieties, ranging from 1.47 per cent in Woodruff to 8.04 in Jefferson and Delaware. In two varieties the range of variation is between 1 and 2 per cent of sugar; in twenty-five it is 2 to 4 per cent; in sixteen, 4 to 6 per cent; in three, 6 to 8 per cent; and in two the variation exceeds 8 per cent. It might be assumed that a narrow range of variation in sugar content indicated perfect adaptation to the local conditions while a wide range indicated that the variety was out of its proper environment or subject to a variable factor such as disease attack. This assumption is scarcely borne out by the facts, since among the varieties showing a range of variation of 3 per cent or less are Concord, Cynthiana, Elvira, Martha, and Woodruff, while those showing a range of 6 to more than 8 per cent are Agawam, Brighton, Delaware, Eumelan, Jefferson, and Nectar. Of these, Cynthiana is the only distinctively Southern variety, Nectar is the only one of the group lacking in vegetative vigor and resistance to disease, and Woodruff is the only one which is susceptible to injury by spraying or fails to ripen its fruit uniformly and with characteristic color. The others are varieties which are well adapted to the Vineland region, as shown by their vigor and productiveness and freedom from insect or fungus attack. The explanation of the wide range of variation in the six varieties last named would appear to be fairly clear. All are midseason or late maturing at Vineland. Two years, 1919 and 1923, were exceptionally favorable for the maturing and ripening of long-season varieties, and the maximum sugar content for four of these occurred in 1923, for the other two in 1919. The maximum for three of the six varieties occurred in 1922, the least favorable year of the period. Additional evidence that these wide variations in sugar content are attributable to the variations in seasonal conditions will be brought out in the subsequent discussion.

With the exception of the six varieties just mentioned, the range of variation in sugar content is from 1 to 6 per cent. Hartmann and Tolman (*27*) analyzed samples of 104 commercial juices of Concord grapes, collected at factories during the season of 1912, 1913, and 1914, and representing the Hudson River district, the Chatauqua belt, and the Lake Erie district. These samples had sugar contents ranging from 11.41 to 17.53 per cent, a range of 6.12 per cent. Alwood and his collaborators (*2*, *3*, *6*, *7*) made analyses of a very large number of varieties of

TABLE III.—*Analytical data for 49 varieties fruiting annually, 1919 to 1923, at Vineland, N. J.*

| | Year | Date picked | Reducing sugar | Cane sugar | Total sugar after inversion [a] | Acid as tartaric | Total astringency | Tannin | Non-tannin | Total solids | Acid-sugar ratio | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Grams per liter* | *Grams per liter* | *Grams per liter* | | | |
| Agawam | 1919 | Sept. 22 | 16.26 | 0.0 | 16.26 | 0.742 | | | | | 1:21.9 | |
| | 1920 | Sept. 18 | 15.02 | .0 | 15.02 | 1.237 | | | | | 1:12.1 | |
| | 1921 | Sept. 23 | 15.91 | .25 | 16.16 | .862 | 1.451 | 0.614 | 0.813 | 18.04 | 1:18.6 | Unaffected by frost. |
| | 1922 | Sept. 16 | 12.94 | .26 | 13.20 | .937 | 1.268 | .258 | 1.010 | | 1:14.0 | |
| | 1923 | Sept. 23 | 18.38 | 1.76 | 20.14 | .894 | .880 | .256 | .624 | 21.16 | 1:22.5 | |
| Barry | 1919 | Sept. 22 | 13.17 | .29 | 13.46 | .828 | | | | | 1:16.2 | |
| | 1920 | Sept. 27 | 13.48 | .0 | 13.48 | 1.335 | | | | | 1:10.1 | |
| | 1921 | Sept. 19 | 11.28 | 1.81 | 13.09 | 1.350 | 1.623 | .464 | 1.159 | 16.21 | 1:9.7 | 85 per cent of normal crop. |
| | 1922 | Sept. 22 | 13.88 | .59 | 14.47 | 1.323 | 2.002 | .742 | 1.260 | | 1:10.9 | |
| | 1923 | Sept. 26 | 16.47 | .0 | 16.47 | 1.048 | 1.094 | .551 | .543 | 17.16 | 1:15.6 | |
| Berckmans | 1919 | Sept. 30 | 18.00 | .0 | 18.00 | 1.155 | | | | | 1:15.5 | Ripens irregularly. |
| | 1920 | Oct. 1 | 17.72 | .0 | 17.72 | 1.132 | | | | | 1:13.5 | |
| | 1921 | Sept. 26 | 16.09 | .0 | 16.09 | 1.192 | .884 | .288 | .596 | 17.86 | 1:13.5 | 75 per cent of a crop. |
| | 1922 | Sept. 23 | 19.12 | 1.10 | 20.22 | 1.508 | .958 | .259 | .699 | | 1:12.1 | |
| | 1923 | Sept. 27 | 15.57 | .78 | 16.35 | 1.186 | .684 | .196 | .488 | 16.72 | 1:13.8 | |
| Brighton | 1919 | Sept. 22 | 23.08 | .0 | 23.08 | .570 | | | | 24.16 | 1:40.5 | |
| | 1920 | Sept. 20 | 16.96 | .0 | 16.96 | .660 | | | | | 1:25.7 | |
| | 1921 | Sept. 24 | 17.20 | .0 | 17.20 | .637 | 1.392 | .428 | .964 | | 1:27.0 | 40 per cent of a crop. |
| | 1922 | Sept. 19 | 18.62 | .0 | 18.62 | .758 | 1.657 | .733 | .924 | | 1:23.8 | |
| | 1923 | Sept. 18 | 21.84 | .54 | 22.38 | .737 | 1.051 | .453 | .598 | 23.66 | 1:30.3 | |
| Brilliant | 1919 | Sept. 26 | 17.62 | .0 | 17.62 | .645 | | | | 20.08 | 1:27.3 | |
| | 1920 | Sept. 25 | 15.80 | .0 | 15.80 | .840 | | | | | 1:18.8 | |
| | 1921 | Sept. 20 | 20.32 | .0 | 20.32 | .622 | 1.162 | .259 | .903 | | 1:31.4 | 35 per cent of a crop. |
| | 1922 | Sept. 19 | 15.16 | .20 | 15.36 | .678 | 1.295 | .648 | .647 | | 1:22.6 | |
| | 1923 | Sept. 21 | 18.94 | .0 | 18.94 | .687 | .897 | .367 | .530 | 20.16 | 1:27.1 | |
| Canada | 1919 | Sept. 22 | 17.42 | .0 | 17.42 | .952 | | | | 18.98 | 1:18.3 | |
| | 1920 | Oct. 15 | 18.32 | .0 | 18.32 | 1.125 | | | | | 1:16.2 | |
| | 1921 | Sept. 24 | 14.93 | .07 | 15.00 | .975 | 1.564 | .406 | 1.158 | | 1:15.3 | 30 per cent of a crop. |
| | 1922 | Sept. 28 | 13.86 | .0 | 13.86 | 1.150 | 1.389 | .733 | .656 | | 1:11.2 | |
| | 1923 | Oct. 2 | 16.49 | .87 | 17.36 | .993 | .820 | .196 | .624 | 18.98 | 1:17.4 | |
| Catawba | 1919 | Oct. 7 | 20.66 | .0 | 20.66 | .945 | | | | | 1:21.8 | |
| | 1920 | Oct. 16 | 16.49 | 1.91 | 18.40 | .820 | | | | 21.64 | 1:22.4 | |
| | 1921 | Sept. 28 | 16.85 | .03 | 16.88 | 1.087 | 1.539 | .548 | .981 | | 1:15.6 | 75 per cent of a crop. |
| | 1922 | Sept. 27 | 15.60 | 1.04 | 16.64 | 1.093 | 1.156 | .258 | .898 | | 1:15.3 | Did not color well. |
| | 1923 | Oct. 6 | 18.37 | .65 | 19.02 | 1.233 | 1.316 | .547 | .769 | 19.94 | 1:15.4 | |
| Clevener | 1919 | Oct. 3 | 13.74 | .0 | 13.74 | 1.222 | | | | 16.21 | 1:10.6 | |
| | 1920 | Oct. 12 | 15.46 | .0 | 15.46 | 1.425 | | | | | 1:10.8 | |
| | 1921 | Sept. 28 | 11.91 | .78 | 12.69 | 1.335 | 2.462 | .559 | 1.903 | | 1:9.5 | About 75 per cent of a crop. |
| | 1922 | Sept. 26 | 12.72 | .69 | 13.41 | 1.766 | 1.821 | .432 | 1.389 | | 1:7.6 | |
| | 1923 | Oct. 6 | 13.00 | .10 | 13.10 | 2.097 | 2.671 | .987 | 1.684 | 15.48 | 1:6.2 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clinton | 1919 | Oct. 7 | 22.44 | .0 | 22.44 | 1.530 | | | | | 1:14.0 | |
| | 1920 | Oct. 9 | 19.96 | .0 | 19.96 | 1.687 | | | | 21.46 | 1:11.7 | |
| | 1921 | Sept. 27 | 16.40 | .62 | 17.02 | 1.665 | 1.720 | .410 | 1.310 | | 1:10.2 | About 65 per cent of a crop. |
| | 1922 | Sept. 21 | 17.03 | 1.22 | 18.25 | 1.760 | 1.752 | .544 | 1.208 | | 1:10.4 | |
| | 1923 | Oct. 10 | 19.62 | 1.30 | 20.92 | 1.653 | 1.111 | .076 | 1.035 | 21.78 | 1:13.2 | |
| Colerain | 1919 | Sept. 18 | 12.78 | 2.84 | 15.62 | .675 | | | | | 1:23.1 | |
| | 1920 | Sept. 22 | 12.76 | .0 | 12.76 | .937 | | | | 16.21 | 1:13.6 | |
| | 1921 | Sept. 19 | 16.02 | .32 | 16.34 | .750 | 1.267 | .394 | .873 | | 1:21.7 | 35 per cent of a crop. |
| | 1922 | Sept. 14 | 12.54 | .0 | 12.54 | .792 | 1.234 | .415 | .819 | | 1:15.5 | |
| | 1923 | Sept. 25 | 15.18 | 1.80 | 16.98 | .648 | 1.051 | .479 | .572 | 17.99 | 1:26.2 | |
| Concord | 1919 | ...do | 15.02 | .0 | 15.02 | .795 | | | | 16.97 | 1:16.3 | |
| | 1920 | ...do | 13.23 | .21 | 13.44 | .825 | | | | | 1:16.1 | |
| | 1921 | Sept. 16 | 14.13 | .16 | 14.29 | .915 | 1.273 | .397 | .876 | | 1:15.6 | 65 per cent of a crop. |
| | 1922 | Sept. 21 | 13.91 | .08 | 13.99 | 1.178 | 1.873 | .872 | 1.001 | | 1:10.9 | |
| | 1923 | Sept. 19 | 14.68 | .52 | 15.20 | .767 | .936 | .440 | .496 | 16.52 | 1:19.8 | |
| Cynthiana | 1919 | Oct. 6 | 17.46 | .0 | 17.46 | 1.285 | | | | | 1:13.6 | |
| | 1920 | Oct. 7 | 16.50 | .0 | 16.50 | 1.335 | | | | 18.04 | 1:12.4 | |
| | 1921 | Sept. 27 | 14.46 | 4.65 | 19.11 | 1.155 | 1.276 | .253 | 1.023 | | 1:16.4 | Normal crop. |
| | 1922 | Sept. 26 | 17.02 | .75 | 17.77 | 1.732 | 1.398 | .499 | .899 | | 1:10.2 | |
| | 1923 | Oct. 8 | 16.90 | 1.92 | 18.82 | 1.269 | 1.222 | .538 | .684 | 19.86 | 1:14.8 | |
| Dakota | 1919 | Oct. 5 | 12.22 | .08 | 12.30 | .787 | | | | 15.07 | 1:15.6 | |
| | 1920 | | | | | | | | | | | Normal crop but no samples secured. |
| | 1921 | Sept. 24 | 13.74 | .0 | 13.74 | 1.365 | 1.372 | .211 | 1.161 | | 1:10.1 | 50 per cent of a crop. |
| | 1922 | Sept. 16 | 14.86 | .10 | 14.96 | 1.463 | 1.450 | .423 | 1.027 | | 1:10.0 | |
| | 1923 | Sept. 22 | 15.14 | 1.65 | 17.39 | 1.299 | .880 | .171 | .709 | 19.08 | 1:13.4 | |
| Diamond | 1919 | ...do | 17.16 | .0 | 17.16 | .990 | | | | | 1:17.1 | |
| | 1920 | Sept. 18 | 13.74 | .0 | 13.74 | .885 | | | | 16.06 | 1:15.5 | |
| | 1921 | Sept. 19 | 14.76 | .0 | 14.76 | .787 | 1.263 | .394 | .869 | | 1:18.2 | 20 per cent of a crop. |
| | 1922 | Sept. 16 | 11.63 | .29 | 11.92 | .908 | 1.571 | .648 | .923 | | 1:12.9 | |
| | 1923 | Sept. 17 | 12.70 | .55 | 13.25 | 1.109 | .940 | .174 | .766 | 13.98 | 1:11.9 | |
| Diana | 1919 | Sept. 23 | 17.28 | .0 | 17.28 | .690 | | | | 19.00 | 1:24.7 | |
| | 1920 | Oct. 13 | 16.94 | .0 | 16.94 | 1.012 | | | | | 1:16.7 | Did not color normally. |
| | 1921 | Sept. 29 | 18.25 | .0 | 18.25 | .795 | .993 | .303 | .690 | | 1:22.9 | 25 per cent of a crop. |
| | 1922 | Sept. 27 | 16.28 | .68 | 16.96 | .968 | .899 | .174 | .725 | | 1:17.5 | |
| | 1923 | Oct. 10 | 15.72 | .0 | 15.72 | .897 | .581 | .205 | .376 | 16.74 | 1:17.0 | Did not color well. |
| Diogenes | 1919 | Sept. 24 | 14.51 | .75 | 15.26 | 1.485 | | | | | 1:10.2 | |
| | 1920 | Oct. 6 | 15.74 | .0 | 15.74 | .982 | | | | 18.21 | 1:16.0 | |
| | 1921 | Sept. 28 | 14.03 | .42 | 14.45 | 1.230 | 2.023 | .594 | 1.429 | | 1:11.7 | 65 per cent of a crop. |
| | 1922 | Sept. 25 | 14.29 | .53 | 14.82 | 1.803 | 1.303 | .336 | .967 | | 1: 8.2 | |
| | 1923 | Oct. 7 | 15.69 | 1.35 | 17.04 | 1.743 | 1.812 | .427 | 1.385 | 18.41 | 1: 9.8 | |
| Delaware | 1919 | Sept. 18 | 16.82 | .39 | 17.21 | .832 | | | | 21.21 | 1:20.7 | |
| | 1920 | Sept. 23 | 17.25 | .0 | 17.27 | .840 | | | | | 1:20.5 | |
| | 1921 | | | | | | | | | | | Partial crop picked prematurely and no samples secured. |
| | 1922 | Sept. 20 | 18.36 | .0 | 18.36 | .696 | .730 | .176 | .554 | | 1:25.6 | |
| | 1923 | Sept. 26 | 24.80 | .45 | 25.25 | .770 | .684 | .154 | .530 | 26.08 | 1:32.8 | Overripe. |
| Dutchess | 1919 | Oct. 1 | 17.03 | .0 | 17.00 | .526 | | | | 18.93 | 1:32.3 | |
| | 1920 | Oct. 14 | 18.72 | .0 | 18.72 | .731 | | | | | 1:25.6 | |
| | 1921 | Sept. 26 | 15.76 | .0 | 15.76 | .735 | .873 | .222 | .651 | | 1:20.2 | |
| | 1922 | ...do | 14.68 | .14 | 14.82 | .900 | 1.260 | .561 | .699 | | 1:16.4 | |
| | 1923 | Oct. 1 | 15.76 | 1.77 | 17.53 | .527 | .538 | .136 | .402 | 19.58 | 1:29.8 | |

* The total sugar after inversion is occasionally slightly less than the free reducing sugar, due to a small loss of levulose during inversion.

TABLE III.—*Analytical data for 49 varieties fruiting annually, 1919 to 1923, at Vineland, N. J.*—Continued

| | Year | Date picked | Reducing sugar | Cane sugar | Total sugar after inversion | Acid as tartaric | Total astringency | Tannin | Non-tannin | Total solids | Acid-sugar ratio | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Grams per liter* | *Grams per liter* | *Grams per liter* | | | |
| Elvira | 1919 | Sept. 19 | 14.84 | .0 | 14.84 | 1.290 | | | | 16.64 | 1:11.5 | Does not ripen uniformly; cracks and rots. |
| | 1920 | Sept. 29 | 14.54 | .0 | 14.54 | .847 | | | | | 1:17.1 | |
| | 1921 | Sept. 17 | 14.26 | .43 | 14.69 | .998 | .944 | .231 | .713 | | 1:12.3 | 50 per cent of a crop. |
| | 1922 | Sept. 16 | 13.54 | .0 | 13.54 | 1.011 | 1.484 | .854 | .630 | | 1:12.8 | |
| | 1923 | Sept. 24 | 15.38 | .0 | 15.38 | .775 | .662 | .175 | .487 | 16.32 | 1:19.2 | |
| Eumelan | 1919 | Sept. 29 | 22.04 | 1.09 | 23.13 | .555 | | | | | 1:41.7 | |
| | 1920 | Oct. 4 | 19.61 | .0 | 19.61 | .607 | | | | 21.64 | 1:32.3 | |
| | 1921 | Sept. 29 | 16.02 | .0 | 16.02 | .660 | .994 | .168 | .826 | | 1:23.7 | 75 per cent of a crop. |
| | 1922 | Sept. 25 | 18.28 | 1.12 | 19.40 | .761 | 1.346 | .250 | 1.096 | 21.93 | 1:25.5 | |
| | 1923 | Oct. 7 | 17.84 | 2.18 | 20.02 | .828 | .768 | .178 | .590 | | 1:24.1 | |
| Franklin | 1919 | Oct. 3 | 15.06 | .0 | 15.06 | 1.200 | | | | | 1:11.7 | |
| | 1920 | Oct. 11 | 13.10 | .36 | 13.46 | 1.380 | | | | 16.83 | 1: 9.7 | |
| | 1921 | Sept. 28 | 8.80 | 3.03 | 11.83 | 1.415 | 1.693 | .196 | 1.497 | | 1: 8.3 | Unaffected by frost. |
| | 1922 | Sept. 26 | 11.96 | .0 | 11.96 | 1.593 | 1.605 | .388 | 1.217 | | 1: 7.5 | |
| | 1923 | Oct. 6 | 16.78 | .92 | 17.70 | 1.689 | 1.684 | .359 | 1.325 | 18.92 | 1:10.5 | |
| Goethe | 1919 | Oct. 1 | 13.75 | .05 | 13.80 | .945 | | | | 16.21 | 1:14.6 | |
| | 1920 | Oct. 4 | 12.25 | 2.04 | 14.29 | .862 | | | | | 1:16.5 | |
| | 1921 | Sept. 22 | 16.00 | .0 | 16.00 | .765 | 1.002 | .404 | .598 | | 1:20.9 | 40 per cent of a crop. |
| | 1922 | Sept. 23 | 14.98 | .0 | 14.98 | .880 | 1.450 | .751 | .699 | | 1:16.7 | |
| | 1923 | Sept. 27 | 14.46 | .13 | 14.59 | .803 | .984 | .471 | .513 | 16.08 | 1:18.1 | |
| Herbemont | 1919 | Oct. 6 | 15.02 | .18 | 15.20 | 1.241 | | | | 17.71 | 1:12.2 | |
| | 1920 | Oct. 16 | 16.64 | .0 | 16.64 | 1.425 | | | | | 1:11.7 | |
| | 1921 | Sept. 28 | 15.97 | .26 | 16.23 | 1.192 | 1.221 | .266 | .955 | | 1:13.6 | |
| | 1922 | Oct. 2 | 16.70 | .06 | 16.76 | 1.272 | 1.303 | .604 | .699 | | 1:13.1 | |
| | 1923 | Oct. 7 | 15.38 | 1.85 | 17.23 | 1.311 | .761 | .368 | .393 | 18.56 | 1:13.1 | |
| Herbert | 1919 | Sept. 29 | 13.62 | 1.21 | 14.83 | .735 | | | | 16.29 | 1:20.2 | |
| | 1920 | Sept. 27 | 15.66 | .0 | 15.66 | 1.072 | | | | | 1:14.6 | |
| | 1921 | Sept. 22 | 14.20 | .88 | 15.08 | .840 | 1.293 | .417 | .876 | | 1:17.9 | 65 per cent of a crop. |
| | 1922 | Sept. 23 | 16.02 | .0 | 16.02 | .982 | 1.173 | .258 | .915 | | 1:16.1 | |
| | 1923 | Sept. 24 | 17.39 | .0 | 17.39 | .822 | .940 | .248 | .692 | 18.86 | 1:21.1 | |
| Isabella | 1919 | Sept. 29 | 13.85 | 2.79 | 16.64 | .780 | | | | 18.23 | 1:21.3 | |
| | 1920 | Oct. 15 | 12.25 | 4.10 | 16.35 | 1.087 | | | | | 1:15.0 | |
| | 1921 | Sept. 29 | 17.56 | .0 | 17.56 | .900 | .926 | .322 | .604 | | 1:19.5 | |
| | 1922 | Sept. 28 | 16.18 | .44 | 16.62 | 1.195 | .949 | .242 | .707 | | 1:14.0 | |
| | 1923 | Oct. 6 | 16.90 | 1.63 | 18.53 | 1.327 | .932 | .359 | .573 | 18.84 | 1:13.9 | |
| Ives | 1919 | Sept. 25 | 15.67 | | 15.67 | .547 | | | | | 1:28.0 | Overripe and shrivelled. |
| | 1920 | Sept. 18 | 13.85 | .04 | 13.89 | .750 | | | | | 1:18.5 | |
| | 1921 | | | | | | | | | | | |
| | 1922 | Sept. 19 | 11.74 | 1.22 | 12.96 | 1.424 | 1.856 | .605 | 1.251 | 16.24 | 1: 9.1 | |
| | 1923 | Sept. 16 | 13.59 | 2.80 | 16.39 | .772 | 1.008 | .136 | .872 | 17.58 | 1:20.7 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jefferson | 1919 | Sept. 23 | 17.50 | ------- | 17.50 | .787 | ------- | ------- | ------- | 19.62 | 1:22.2 | |
| | 1920 | Oct. 4 | 12.25 | 2.01 | 14.26 | .765 | ------- | ------- | ------- | ------- | 1:18.6 | |
| | 1921 | Sept. 24 | 13.11 | ------- | 13.11 | .652 | .933 | .309 | .622 | ------- | 1:20.0 | 60 per cent of a crop. |
| | 1922 | Sept. 18 | 11.57 | .80 | 12.37 | .752 | 1.199 | .250 | .949 | ------- | 1:16.4 | Cracking and rotting badly, hence picked slightly underripe. |
| | 1923 | Oct. 8 | 17.96 | 2.45 | 20.41 | .835 | .761 | .163 | .598 | 21.92 | 1:24.4 | |
| Lampasas | 1919 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | Crop picked prematurely; no samples secured. |
| | 1920 | Sept. 25 | 14.79 | 0.0 | 14.79 | .750 | ------- | ------- | ------- | 17.21 | 1:19.6 | |
| | 1921 | Sept. 19 | 15.49 | 2.05 | 17.54 | .742 | .861 | .057 | .804 | ------- | 1:23.6 | 30 per cent of a crop. |
| | 1922 | Sept. 21 | 13.74 | .40 | 14.14 | .701 | 1.148 | .130 | 1.018 | ------- | 1:20.1 | |
| | 1923 | Oct. 6 | 12.78 | 1.70 | 14.48 | .944 | .863 | .242 | .621 | 15.72 | 1:15.3 | |
| Lenoir | 1919 | ...do.... | 11.98 | 2.71 | 14.69 | 1.650 | ------- | ------- | ------- | 18.89 | 1: 8.9 | |
| | 1920 | Oct. 15 | 14.43 | 1.70 | 16.13 | 1.560 | ------- | ------- | ------- | ------- | 1:10.3 | |
| | 1921 | Sept. 28 | 16.64 | ------- | 16.64 | 1.560 | 1.523 | .417 | 1.106 | ------- | 1:10.6 | Normal crop. |
| | 1922 | Oct. 2 | 13.72 | 0.0 | 13.72 | 2.047 | 1.027 | .388 | .639 | ------- | 1: 6.6 | |
| | 1923 | Oct. 6 | 15.84 | 1.74 | 17.58 | 1.537 | .970 | .432 | .538 | 19.52 | 1:11.4 | |
| Lindley | 1919 | Sept. 29 | 20.36 | 0.0 | 20.36 | .547 | ------- | ------- | ------- | 21.89 | 1:37.1 | |
| | 1920 | Sept. 27 | 14.61 | 0.0 | 14.61 | .675 | ------- | ------- | ------- | ------- | 1:21.6 | |
| | 1921 | Sept. 22 | 14.02 | .98 | 15.00 | .605 | 1.326 | .167 | 1.159 | ------- | 1:24.8 | 60 per cent of a crop. |
| | 1922 | ...do.... | 15.12 | .40 | 15.52 | .735 | 1.778 | .346 | 1.432 | ------- | 1:21.0 | |
| | 1923 | Sept. 26 | 17.30 | .22 | 17.52 | .739 | .880 | .256 | .624 | 18.32 | 1:23.7 | |
| Lucile | 1919 | Sept. 20 | 18.35 | 0.0 | 18.35 | .630 | ------- | ------- | ------- | ------- | 1:29.1 | |
| | 1920 | ...do.... | 14.06 | 0.0 | 14.06 | .750 | ------- | ------- | ------- | ------- | 1:18.7 | |
| | 1921 | Sept. 19 | 13.14 | 1.68 | 14.82 | .600 | 1.441 | .279 | 1.162 | 18.61 | 1:24.7 | 50 per cent of a crop. |
| | 1922 | Sept. 14 | 11.66 | .67 | 12.33 | .684 | 1.312 | .363 | .949 | ------- | 1:18.4 | |
| | 1923 | Sept. 18 | 14.60 | .76 | 15.36 | .764 | .957 | .316 | .641 | 16.48 | 1:20.1 | |
| Martha | 1919 | Sept. 20 | 17.37 | .13 | 17.50 | .570 | ------- | ------- | ------- | ------- | 1:30.7 | |
| | 1920 | ...do.... | 19.02 | 0.0 | 18.91 | .600 | ------- | ------- | ------- | 20.20 | 1:31.6 | |
| | 1921 | Sept. 17 | 17.97 | 1.04 | 19.01 | .547 | 1.299 | .313 | .986 | ------- | 1:34.7 | 25 per cent of a crop. |
| | 1922 | Sept. 15 | 16.66 | .31 | 16.97 | .537 | 1.449 | .413 | 1.036 | ------- | 1:31.6 | |
| | 1923 | ...do.... | 15.83 | .23 | 16.06 | .621 | 1.226 | .264 | .962 | 19.04 | 1:25.8 | |
| Massasoit | 1919 | Sept. 29 | 14.67 | 0.0 | 14.67 | .570 | ------- | ------- | ------- | ------- | 1:25.7 | |
| | 1920 | Sept. 24 | 12.49 | 0.0 | 12.46 | .990 | ------- | ------- | ------- | ------- | 1:12.5 | |
| | 1921 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | |
| | 1922 | Sept. 22 | 13.02 | .42 | 13.44 | .908 | 1.994 | .648 | 1.346 | 15.02 | 1:14.9 | |
| | 1923 | Oct. 1 | 14.26 | 0.0 | 14.21 | .629 | .812 | .352 | .470 | 15.00 | 1:22.6 | |
| Merrimac | 1919 | Sept. 22 | 13.74 | 3.08 | 16.82 | .720 | ------- | ------- | ------- | 17.83 | 1:23.3 | |
| | 1920 | ...do.... | 15.84 | 0.0 | 15.84 | .825 | ------- | ------- | ------- | ------- | 1:19.2 | |
| | 1921 | Sept. 24 | 17.67 | 0.0 | 17.54 | .829 | 1.064 | .281 | .783 | ------- | 1:21.0 | Do. |
| | 1922 | Sept. 21 | 13.38 | .16 | 13.54 | .886 | 1.148 | .329 | .819 | ------- | 1:14.9 | |
| | 1923 | Sept. 23 | 17.29 | .02 | 17.31 | .855 | .829 | .231 | .598 | 18.80 | 1:20.2 | |
| Missouri Riesling | 1919 | Sept. 20 | 18.66 | 0.0 | 18.66 | 1.080 | ------- | ------- | ------- | ------- | 1:17.0 | |
| | 1920 | Sept. 29 | 17.70 | .62 | 17.72 | 1.125 | ------- | ------- | ------- | 19.23 | 1:15.7 | |
| | 1921 | Sept. 19 | 17.92 | 0.0 | 17.92 | 1.050 | .762 | .161 | .601 | ------- | 1:17.0 | Unaffected by frost. |
| | 1922 | Sept. 18 | 13.64 | 0.0 | 13.61 | .989 | 1.286 | .855 | .431 | ------- | 1:13.7 | |
| | 1923 | Sept. 20 | 15.92 | .20 | 16.12 | .891 | .581 | .060 | .521 | 17.30 | 1:17.8 | |
| Montefiore | 1919 | Sept. 24 | 19.00 | 0.0 | 18.93 | .750 | ------- | ------- | ------- | ------- | 1:25.1 | |
| | 1920 | ...do.... | 16.11 | 0.0 | 16.01 | .637 | ------- | ------- | ------- | 18.21 | 1:25.1 | |
| | 1921 | Sept. 20 | 15.97 | 1.53 | 17.50 | .780 | 1.718 | .554 | 1.164 | ------- | 1:22.4 | 60 per cent of a crop. |
| | 1922 | ...do.... | 15.28 | .30 | 15.58 | 1.082 | 2.511 | 1.001 | 1.510 | ------- | 1:14.4 | |
| | 1923 | Sept. 25 | 16.79 | .92 | 17.71 | .555 | 1.128 | .410 | .718 | 19.88 | 1:31.9 | |

TABLE III.—*Analytical data for 49 varieties fruiting annually, 1919 to 1923, at Vineland, N. J.*—Continued

| | Year | Date picked | Reducing sugar | Cane sugar | Total sugar after inversion | Acid as tartaric | Total astringency | Tannin | Non-tannin | Total solids | Acid-sugar ratio | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Grams per liter* | *Grams per liter* | *Grams per liter* | | | |
| Nectar | 1919 | Sept. 23 | 17.78 | 0.0 | 17.78 | .757 | | | | | 1:23.3 | |
| | 1920 | Sept. 20 | 17.60 | 0.0 | 17.52 | 1.072 | | | | | 1:16.2 | |
| | 1921 | Sept. 24 | 13.04 | 2.93 | 15.97 | .982 | 1.910 | .629 | 1.281 | 19.04 | 1:16.2 | Normal crop. |
| | 1922 | Sept. 22 | 13.94 | .15 | 14.09 | 1.289 | 4.012 | 2.347 | 1.665 | | 1:10.9 | Immature. |
| | 1923 | Sept. 16 | 18.58 | 1.59 | 20.17 | .833 | 1.410 | .709 | .701 | 21.54 | 1:24.2 | Overripe. |
| Niagara | 1919 | Sept. 25 | 15.54 | .24 | 15.78 | .622 | | | | | 1:25.3 | |
| | 1920 | Sept. 29 | 15.98 | 0.0 | 16.00 | .705 | | | | 18.83 | 1:22.7 | |
| | 1921 | Sept. 20 | 17.00 | 0.0 | 17.00 | .607 | 1.267 | .141 | 1.126 | | 1:28.0 | |
| | 1922 | Sept. 21 | 14.25 | .33 | 14.58 | .664 | 1.182 | .189 | .993 | | 1:21.9 | |
| | 1923 | Sept. 22 | 15.54 | .56 | 16.10 | .750 | .778 | .129 | .649 | 17.50 | 1:21.6 | |
| Noah | 1919 | Sept. 25 | 15.12 | 1.02 | 16.14 | 1.462 | | | | | 1:11.0 | |
| | 1920 | Sept. 30 | 17.26 | 1.47 | 18.73 | 1.127 | | | | 20.12 | 1:16.6 | |
| | 1921 | Sept. 23 | 16.87 | 0.0 | 16.87 | 1.230 | 1.004 | .111 | .893 | | 1:13.7 | Normal crop. |
| | 1922 | Sept. 22 | 17.09 | .53 | 17.62 | 1.178 | 1.320 | .327 | .993 | | 1:14.9 | |
| | 1923 | Oct. 1 | 18.64 | .91 | 19.55 | 1.212 | .718 | .282 | .436 | 20.76 | 1:16.1 | |
| Norton | 1919 | Oct. 6 | 21.47 | .0 | 21.47 | 1.567 | | | | | 1:13.7 | |
| | 1920 | Oct. 8 | 19.17 | .0 | 19.16 | 1.462 | | | | 21.40 | 1:13.1 | |
| | 1921 | Sept. 27 | 20.80 | .0 | 20.80 | 1.200 | 1.443 | .381 | 1.062 | | 1:17.3 | Do. |
| | 1922 | Sept. 28 | 18.28 | 1.10 | 19.38 | 1.828 | 1.562 | .475 | 1.087 | | 1:10.6 | |
| | 1923 | Oct. 3 | 17.70 | 2.54 | 20.54 | 1.148 | 1.248 | .453 | .795 | 21.96 | 1:17.6 | |
| Perkins | 1919 | Sept. 22 | 13.48 | .0 | 13.48 | .600 | | | | 15.04 | 1:22.5 | |
| | 1920 | Sept. 18 | 12.42 | .0 | 12.40 | .840 | | | | | 1:14.8 | |
| | 1921 | Sept. 27 | 9.82 | 3.39 | 13.21 | .690 | 1.269 | .165 | 1.104 | | 1:19.1 | 50 per cent of a crop. |
| | 1922 | Sept. 18 | 9.50 | 1.51 | 11.01 | .673 | 1.286 | .423 | .863 | | 1:16.3 | |
| | 1923 | Oct. 1 | 13.73 | .70 | 14.43 | .555 | .897 | .282 | .615 | 15.20 | 1:26.0 | |
| Pocklington | 1919 | Sept. 26 | 15.79 | .0 | 15.63 | .660 | | | | | 1:23.6 | |
| | 1920 | Oct. 2 | 13.25 | 1.61 | 14.86 | .787 | | | | | 1:18.9 | |
| | 1921 | Sept. 20 | 16.10 | .50 | 16.60 | .720 | 1.321 | .220 | 1.101 | 18.31 | 1:23.0 | |
| | 1922 | Sept. 15 | 11.98 | .87 | 12.85 | 1.067 | 1.554 | .605 | .949 | | 1:12.0 | |
| | 1923 | Sept. 25 | 13.17 | 1.76 | 14.93 | .751 | .983 | .496 | .487 | 15.82 | 1:19.8 | |
| Rommel | 1919 | Sept. 22 | 11.72 | 1.57 | 13.29 | .822 | | | | | 1:16.1 | |
| | 1920 | Sept. 28 | 10.98 | 2.54 | 13.52 | .840 | | | | | 1:16.1 | |
| | 1921 | Sept. 26 | 15.41 | .0 | 15.41 | .817 | .944 | .210 | .734 | 17.26 | 1:18.8 | 35 per cent of a crop. |
| | 1922 | Sept. 19 | 13.18 | .46 | 13.64 | .977 | 1.199 | .232 | .967 | | 1:13.9 | |
| | 1923 | Oct. 3 | 12.76 | 1.80 | 14.56 | .659 | .769 | .333 | .436 | 16.30 | 1:22.0 | |
| Salem | 1919 | Sept. 26 | 21.58 | .0 | 21.58 | .780 | | | | 22.98 | 1:27.6 | |
| | 1920 | Sept. 23 | 13.50 | 2.70 | 16.20 | 1.050 | | | | | 1:15.4 | |
| | 1921 | Sept. 21 | 15.94 | .22 | 16.16 | .862 | 1.234 | .288 | .946 | | 1:18.7 | 75 per cent of a crop. |
| | 1922 | Sept. 23 | 16.90 | .72 | 17.62 | .923 | 1.665 | .811 | .854 | 18.98 | 1:19.1 | |
| | 1923 | Oct. 2 | 17.91 | .94 | 18.85 | .770 | .786 | .303 | .483 | 19.78 | 1:24.4 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ulster | 1919 | Sept. 22 | 16.67 | .0 | 16.67 | .822 | | | | 19.82 | 1:20.3 | |
| | 1920 | Oct. 1 | 12.26 | 3.18 | 15.44 | .975 | | | | | 1:15.8 | |
| | 1921 | Sept. 21 | 14.54 | 1.68 | 16.22 | .813 | .804 | .041 | .763 | | 1:20.0 | |
| | 1922 | ...do | 16.90 | .68 | 17.58 | .965 | 1.182 | .362 | .820 | | 1:18.2 | |
| | 1923 | Oct. 4 | 19.90 | .07 | 19.97 | .748 | .709 | .060 | .649 | 21.04 | 1:26.7 | |
| Vergennes | 1919 | Sept. 30 | 18.84 | .0 | 18.84 | .822 | | | | 20.21 | 1:22.9 | |
| | 1920 | Oct. 9 | 14.62 | .26 | 14.88 | .870 | | | | | 1:17.1 | |
| | 1921 | Sept. 21 | 19.26 | .0 | 19.20 | 1.042 | 1.020 | .209 | .811 | | 1:18.4 | Normal crop. |
| | 1922 | Sept. 23 | 15.08 | .0 | 15.08 | .795 | 1.009 | .396 | .613 | | 1:18.7 | |
| | 1923 | Oct. 5 | 18.70 | .0 | 18.64 | .715 | .709 | .213 | .496 | 19.66 | 1:25.5 | |
| Wilder | 1919 | Sept. 30 | 20.28 | .0 | 20.28 | .570 | | | | | 1:35.1 | |
| | 1920 | Sept. 23 | 12.10 | 2.48 | 14.58 | 1.267 | | | | 17.38 | 1:11.5 | |
| | 1921 | Sept. 21 | 12.73 | 1.95 | 14.68 | .765 | 1.001 | .141 | .860 | | 1:19.2 | Do. |
| | 1922 | Sept. 23 | 14.38 | .0 | 14.38 | .841 | 1.122 | .294 | .828 | | 1:16.7 | |
| | 1923 | Oct. 5 | 15.84 | .61 | 16.45 | .753 | 1.154 | .214 | .940 | 18.64 | 1:21.8 | |
| Woodruff | 1919 | Sept. 26 | 14.53 | .0 | 14.48 | .630 | | | | 16.54 | 1:22.9 | |
| | 1920 | Oct. 2 | 14.26 | .0 | 14.20 | .787 | | | | | 1:18.0 | |
| | 1921 | Sept. 20 | 15.24 | .43 | 15.67 | .757 | 1.228 | .195 | 1.033 | | 1:20.7 | |
| | 1922 | Sept. 16 | 11.79 | 2.62 | 14.41 | .803 | 1.407 | .354 | 1.053 | | 1:17.9 | |
| | 1923 | Sept. 22 | 14.74 | .83 | 15.57 | .646 | .743 | .247 | .496 | 16.58 | 1:24.1 | |
| Worden | 1919 | Sept. 19 | 9.75 | 4.67 | 14.32 | .967 | | | | | 1:14.8 | |
| | 1920 | Sept. 25 | 10.03 | 5.57 | 15.60 | .975 | | | | | 1:16.0 | |
| | 1921 | Sept. 16 | 14.79 | .12 | 14.91 | .582 | 1.369 | .357 | 1.012 | 16.34 | 1:25.6 | 45 per cent of a crop; over ripe. |
| | 1922 | Sept. 15 | 11.44 | .0 | 11.41 | 1.070 | 1.665 | .612 | 1.053 | | 1:10.7 | |
| | 1923 | Sept. 20 | 11.34 | 1.46 | 12.80 | 1.062 | .949 | .222 | .727 | 13.94 | 1:12.0 | |

TABLE IV.—*Analytical data for varieties not fruiting regularly during 1918–1923*

| | Year | Date picked | Reducing sugar | Cane sugar | Total sugar | Acid as tartaric | Total astringency | Tannin | Non-tannin | Total solids | Acid-sugar ratio | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Grams per liter* | *Grams per liter* | *Grams per liter* | | | |
| Campbell | 1919 | Sept. 26 | 16.43 | 0.0 | 16.43 | 0.592 | | | | | 1:27.7 | Very small crop; vines in poor condition. |
| | 1920 | Oct. 1 | 9.92 | 3.73 | 13.65 | .675 | | | | | 1:20.2 | |
| | 1921 | Sept. 20 | 14.34 | .0 | 14.18 | .645 | 0.813 | 0.087 | 0.726 | 16.21 | 1:22.2 | About 40 per cent of a crop. |
| | 1922 | Sept. 15 | 12.78 | .53 | 13.31 | .679 | 1.122 | .216 | .906 | | 1:19.5 | |
| | 1923 | Sept. 17 | 14.32 | 1.65 | 15.97 | .679 | .880 | .333 | .547 | | 1:23.5 | |
| Centennial | 1919 | Sept. 22 | 12.68 | .86 | 13.54 | .975 | | | | | 1:13.9 | |
| | 1920 | | | | | | | | | | | No crop. |
| | 1921 | Sept. 24 | 14.71 | .0 | 14.71 | 1.185 | 1.840 | .619 | 1.221 | | 1:12.4 | 30 per cent of a crop. |
| | 1922 | Sept. 14 | 11.36 | .08 | 11.44 | 1.207 | 1.449 | .535 | .914 | 14.64 | 1:9.5 | |
| | 1923 | Oct. 2 | 17.15 | 2.05 | 19.20 | 1.382 | .914 | .266 | .648 | | 1:13.9 | Overripe and shriveled. |
| Champion | 1921 | Sept. 19 | 12.40 | .0 | 12.24 | 1.215 | 1.193 | .147 | 1.046 | 13.06 | 1:10.0 | |
| | 1922 | Sept. 14 | 8.96 | .41 | 9.37 | .667 | 2.046 | .976 | 1.070 | | 1:14.0 | Badly overripe. |
| | 1923 | Sept. 23 | 11.92 | .05 | 11.97 | 1.294 | 1.043 | .385 | .658 | 12.92 | 1:9.3 | |
| "Dutchess seedling" | 1922 | Sept. 28 | 14.34 | .02 | 14.36 | .669 | .220 | .044 | .176 | | 1:21.4 | No crop prior to 1922. |
| | 1923 | Oct. 2 | 11.98 | 1.87 | 13.85 | .656 | .547 | .086 | .461 | 15.82 | 1:20.1 | |
| Early Daisy | 1919 | Sept. 23 | 12.14 | .9 | 12.23 | .480 | | | | 14.44 | 1:25.4 | Not well matured. |
| | 1920 | | | | | | | | | | | No crop. |
| | 1921 | | | | | | | | | | | Do. |
| | 1922 | Sept. 18 | 15.97 | .0 | 15.96 | .812 | 3.280 | 1.117 | 2.114 | | 1:19.6 | |
| | 1923 | Sept. 23 | 18.34 | 2.50 | 20.84 | .673 | 1.442 | .685 | .757 | 21.30 | 1:30.9 | Very over ripe and soft; juice viscuous. |
| Early Victor | 1919 | do | 14.36 | .05 | 14.41 | .525 | | | | | 1:27.4 | |
| | 1920 | Sept. 20 | 15.28 | .0 | 15.28 | .753 | | | | | 1:20.3 | |
| | 1921 | | | | | | | | | | | No crop. |
| | 1922 | Sept. 14 | 13.49 | .0 | 13.41 | .756 | 1.053 | .234 | .819 | 19.08 | 1:17.7 | |
| | 1923 | Sept. 20 | 13.06 | 1.79 | 14.85 | 1.037 | .936 | .557 | .479 | 16.93 | 1:14.3 | |
| Eaton | 1919 | Sept. 23 | 10.49 | .87 | 11.36 | .877 | | | | 14.20 | 1:12.9 | |
| | 1920 | | | | | | | | | | | Never bears more than a few scattered clusters. |
| | 1921 | | | | | | | | | | | No crop. |
| | 1922 | Sept. 14 | 11.94 | .0 | 11.94 | 1.160 | .704 | .378 | .326 | 14.64 | 1:10.3 | Do. |
| | 1923 | Sept. 20 | 13.06 | 1.79 | 14.85 | 1.037 | .936 | .457 | .479 | | 1:14.3 | |
| Gaertner | 1919 | | | | | | | | | | | |
| | 1920 | Sept. 27 | 14.12 | .0 | 14.06 | .795 | | | | | 1:17.7 | Do. |
| | 1921 | | | | | | | | | | | Never bears more than occasional clusters. |
| | 1922 | Sept. 22 | 13.42 | .0 | 13.32 | .843 | 1.752 | .535 | 1.217 | | 1:15.8 | No crop. |
| | 1923 | Oct. 1 | 15.98 | .0 | 15.95 | .773 | .607 | .086 | .521 | 17.66 | 1:24.5 | Colors very poorly. |
| Hartford | 1922 | Sept. 14 | 12.42 | .24 | 12.66 | .695 | 1.596 | .682 | .914 | | 1:18.2 | |
| | 1923 | Sept. 19 | 13.32 | 2.74 | 16.06 | .654 | 1.043 | .342 | .701 | | 1:24.5 | No crop prior to 1922. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| King Philip | 1920 | Oct. 1 | 10.70 | 3.26 | 13.96 | .750 | | | | | 1:18.6 | Scattered bunches; poorly ripened |
| | 1921 | Sept. 21 | 14.76 | .0 | 14.71 | .743 | .778 | .052 | .726 | | 1:19.8 | |
| | 1922 | Sept. 20 | 14.00 | .0 | 14.00 | .826 | 1.027 | .034 | .993 | | 1:16.9 | |
| | 1923 | Sept. 26 | 17.56 | .0 | 17.42 | .817 | .769 | .316 | .453 | 18.08 | 1:21.3 | |
| Lady | 1919 | Sept. 23 | 14.79 | .23 | 15.02 | .682 | | | | | 1:22.0 | Fails to mature evenly. |
| | 1920 | Sept. 18 | 13.29 | 2.57 | 15.86 | .885 | | | | | 1:17.9 | |
| | 1921 | Sept. 19 | 17.96 | .0 | 17.91 | .787 | .951 | .038 | .813 | 19.01 | 1:22.7 | Scattered bunches only. |
| | 1922 | | | | | | | | | | | No crop. |
| | 1923 | | | | | | | | | | | Do. |
| Moore | 1919 | Sept. 18 | 11.52 | 1.34 | 12.86 | .915 | | | | | 1:14.0 | |
| | 1920 | | | | | | | | | | | Do. |
| | 1921 | | | | | | | | | | | Do. |
| | 1922 | | | | | | | | | | | Do. |
| | 1923 | Sept. 20 | 12.82 | 1.08 | 13.90 | .991 | 1.301 | .385 | .916 | 14.96 | 1:14.0 | |
| Rebecca | 1919 | | | | | | | | | | | Do. |
| | 1920 | | | | | | | | | | | Do. |
| | 1921 | | | | | | | | | | | Do. |
| | 1922 | Sept. 21 | 13.39 | .70 | 14.09 | .650 | 1.208 | .259 | .949 | | 1:21.7 | |
| | 1923 | Oct. 10 | 12.61 | 1.13 | 13.74 | .519 | .675 | .205 | .470 | 14.64 | 1:26.4 | |
| "Seibel Hybrid No. 1" | 1920 | Oct. 13 | 19.14 | .0 | 19.10 | 1.440 | | | | | 1:13.2 | |
| | 1921 | Sept. 27 | 14.67 | .0 | 14.67 | 1.417 | 1.258 | .304 | .954 | | 1:10.3 | |
| | 1922 | Sept. 28 | 13.36 | 1.22 | 14.58 | 1.550 | 1.631 | .612 | 1.019 | 17.23 | 1: 9.4 | |
| | 1923 | Oct. 2 | 16.36 | .0 | 16.36 | 1.587 | 1.282 | .342 | .940 | 17.86 | 1:10.2 | |
| "Seibel Hybrid No. 2" | 1920 | Oct. 13 | 13.38 | .0 | 13.38 | 1.657 | | | | 16.52 | 1: 8.0 | |
| | 1921 | Sept. 27 | 12.20 | 1.52 | 13.72 | 1.305 | 1.423 | .403 | 1.020 | | 1:10.5 | |
| | 1922 | Sept. 29 | 14.38 | .33 | 14.71 | 1.871 | 1.795 | .923 | .872 | | 1: 7.8 | |
| | 1923 | Oct. 8 | 14.88 | 1.30 | 16.18 | 1.821 | 1.436 | .419 | 1.017 | 17.06 | 1: 8.8 | |
| Winchell | 1919 | Sept. 21 | 22.60 | .0 | 22.60 | .465 | | | | 23.13 | 1:48.6 | Overripe and shriveled. |
| | 1920 | | | | | | | | | | | |
| | 1921 | | | | | | | | | | | |
| | 1922 | | | | | | | | | | | |
| | 1923 | Sept. 18 | 20.20 | .66 | 20.86 | .496 | .889 | .325 | .564 | 21.88 | 1:42.0 | Overripe. |

American grapes grown in Ohio, New York, Virginia, Michigan, Pennsylvania, and New Jersey in the years 1908–1913. The number of samples of a variety analyzed by these workers varied from 1 to 15 for the less important varieties to 264 for Catawba, 50 for Clinton, 303 for Concord, 95 for Delaware, 125 for Ives, and 116 for Niagara. These were collected over a period of several years, the samples in some cases containing collections made in the same locality for two or more years in succession and in the case of the more widely grown varieties may be considered to fairly represent their composition as grown in the commercial grape-growing districts of the Central and Eastern States. Naturally no data as to the conditions of the various vineyards represented, or the climatic conditions during the period of the work could be obtained in an experiment covering so large an area, but it is noted (*3*) that in the Ohio grape district the year 1908 was an exceptionally favorable one, that 1909 was characterized both by a very heavy crop and by unpropitious weather during the ripening period, and that 1910 was a year of partial crop failure as a result of late spring frosts. Hence the samples represent a wide range of seasonal conditions and of load on the vines as well as of soils and cultural practices and may be expected to show the extremes encountered in the area represented in the work. The samples were in part taken at wine cellars as the fruit was delivered by wagon or rail, and in part shipped to the laboratory after having been collected by the writers, by cooperating members of Agricultural Experiment Station forces, or by growers, and some errors of sampling were inevitable. The extreme range in sugar content found by Alwood and his associates in the six leading varieties, as assembled by the writer from their published data, were as follows: Catawba—from 12.92 to 22.53 per cent, or 9.61 per cent difference; Clinton—from 11.52 to 23.24 per cent, a range of 11.72 per cent difference; Concord—from 10.41 to 20.48 per cent, a range of 10.07 per cent difference; Delaware—from 16.20 to 26.85 per cent, a range of 10.65 per cent difference; Ives—from 11.17 to 21.22 per cent, a range of 10.05 per cent difference; and Niagara—11.36 to 19.24 per cent, a range of 7.88 per cent difference. While the maximum and minimum figures found for a variety usually occur in different years and in more or less widely separated districts, in the case of Concord they occurred in a group of 23 samples collected at North East, Pa., in 1910. With this exception, the samples of a variety for any given locality and year show much narrower differences, as would be expected.

To sum up by a generalization, the range of differences in percentage of sugar content found by Alwood and his associates in samples of grapes collected from a large number of sources in six States over a five-year period is approximately twice as great as that found by the author in the fruit from one vineyard over a like period. The absolute amounts of sugar present as reported by Alwood are uniformly higher than those found by the writer for the same varieties. This difference is due in part, undoubtedly, to the difference in the method of sampling, Alwood's samples having been crushed and pressed through cheesecloth by hand. It may indicate, however, that grapes grown in the Vineland district of New Jersey regularly develop a somewhat lower sugar content than in the Lake Erie and Chautauqua districts. Alwood and his associates (*7*) analyzed a number of samples from New Jersey in 1913, among them 24 varieties from the Vineland vineyard, and they comment upon them as being low in sugar as compared with the same varieties grown elsewhere. It would require a very comprehensive study, employing rigidly controlled methods of sampling, to definitely determine whether there is a constant difference in composition of a given variety in different localities throughout its range.

## PRESENCE OF CANE SUGAR

The literature dealing with the chemistry of the European grape, *Vitis vinifera*, is in agreement that sucrose is never found in the mature fruit of this species. Such standard works on wine making as Babo and Mach (*11*), Thudichum (*57*), and Laborde (*40*), repeatedly make this statement, and the detailed studies of Famintzin (*21*), Girard and Lindet (*23*), Martinand (*46*), Baragiola and Godet (*12*), and Roos and Hugues (*54*), confirm it. Martinand found invertase present in all parts of vine and fruit and could find no saccharose either in free-run juice or in the pulp of the ripe fruit. Girard and Lindet and Baragiola and Godet found traces of saccharose in developing grapes, none in mature fruit. Roos and Hugues studied the dextrose-levulose ratio in various Vinifera varieties and also in the American varieties Con-

cord, Clinton, Elvira, Isabella, Jacques (Lenoir) Noah, Taylor, Telegraph, and Othello, grown at the oenological station at Montpelier, finding no sucrose present in any of them. Bioletti, Cruess, and Davi (*14*) also found no sucrose in Vinifera varieties grown in California.

Most American students of grapes have proceeded upon the assumption that the native American varieties are like the European Vinifera in being sucrose free, and in the older analytical work and some of more recent date (*13, 26, 42, 53, 61*) upon American varieties no examinations for sucrose were made. It has even been proposed to employ the absence of sucrose as a test for purity in unfermented grape juices (*58*).

The presence of sucrose in considerable amounts in well matured samples of fruit has, however, been reported for a number of American grapes. Gore (*24*) in 1909 found 2 per cent in juice of Mish and 0.69 per cent in Scuppernong juice (two varieties of *Vitis rotundifolia* or "Muscadine" grapes), with probable traces in Concord and Catawba juices, and Alwood (*1, 2, 4, 8*) in the next two years found large amounts in an unnamed seedling with smaller amounts in Catawba, Norton, and Montefiore, Hayes, Worden, Pocklington, Illinois City, and Nectar. Its presence was not correlated with degree of maturity of the fruit. Howard (*34*) reported analyses of 12 samples of grape juice, finding cane sugar in Catawba and in three unlabeled samples which were presumably Concord. Thompson and Whittier (*56*) found 0.5 per cent or more of sucrose in the juice of 5 varieties of grapes examined. Gore (*25*) examined 66 varieties yearly for four years (1911–1914), finding that it was present occasionally in 10, frequently in 13, and absent in 43. The fruit examined by Gore came from the Vineland vineyard, but a number of varieties of the Muscadine grape (*Vitis rotundifolia*) grown at Willard, N. C., were also examined. No sucrose was found at any time in Agawam, Barry, Berckmans, Brighton, Brilliant, Canada, Catawba, Centennial, Clinton, Concord, Cynthiana, Delaware, Diogenes, Dutchess, Early Champion, Eaton, Elvira, Eumelan, Franklin, Gaertner, Goethe, Hartford, Herbemont, "Seibel Hybrid No. 1 or No. 2," Iona, Ives, Jefferson, Lampasas, Lindley, Martha, Massasoit, Merrimac, Missouri Riesling, Montefiore, Niagara, Noah, Norton, Perkins, Salem, Ulster or the Rotundifolia varieties Flowers and James. It was present in all four years in Thomas (Rotundifolia) Pocklington and Nectar; in three years in Early Victor, Lady, Moore Early, Scuppernong (Rotundifolia) and Woodruff; two years in Campbell Early, Colerain, Eden (Rotundifolia), Herbert, and Lenoir; and one year only in Clevener, Diamond, Diana, Early Daisy, Isabella, Rommel, Vergennes, Wilder, Winchell, and Worden. Some of the grapes used were pressed cold and some were heated to 95° C. before pressing, after shipment from the vineyard to Washington. The widespread but very irregular occurrence of sucrose in American grapes is therefore firmly established.

In the course of the present work indications of the presence of at least a trace of cane sugar have been found at some time in every one of the 66 varieties under study except Gaertner. In a few cases the difference in the figures before and after inversion is so slight—0.20 per cent or less—as to make it probable that the differences are due to experimental error. This may be the case for the small amounts found in Brilliant and Champion in 1922, Delaware in 1923, Elvira in 1921, Massasoit in 1922, Missouri Riesling and Vergennes in 1920, as in all these varieties indications of cane sugar appeared only once in the period, but in all these cases the repetition of the test confirmed the first figures obtained. Of the 66 varieties fruiting in 1923, 48 showed positive amounts (0.20 per cent or more) of sucrose; in 1922, 37 out of 63 showed positive amounts; in 1921, 23 out of 53; in 1920, 21 out of 66; and in 1909, 20 out of 59. As the determinations for 1919, 1920, and 1921 were made upon previously pasteurized samples, there is a possibility for the inversion of small amounts of cane sugar where present during the pasteurization. The fact that many of the juices of the varieties from the same vineyard previously examined by Gore had been prepared by heating the fruit prior to pressing may have been responsible for the negative results reported by him for many of these varieties.

That the occurrence of sucrose is exceedingly erratic is indicated by Gore's results as well as by those here reported. In no variety was it invariably present through the five-year period covered by the work. In 15 varieties it occurred only once—Brighton, Brilliant, Canada, Champion, Diana, Delaware, Dutchess, Early Daisy, Early Victor, King Philip, Massasoit, Merrimac, Missouri Riesling, Vergennes, Winchell—and in 7 of these only in 1923. In 16 varieties it was found twice, in 21 varieties 3 times. It was present in four years out of five in the 11 varieties—Ca-

tawba, Diogenes, Franklin, Isabella, Lucile, Noah, Pocklington, Rommel, Salem, Wilder, and Worden. The analyses for three of the five years were made upon previously pasteurized juices and the negative results for cane sugar were obtained with pasteurized samples in which there is a possibility of inversion of cane sugar during pasteurization. This indicates strongly that cane sugar may be normally present in the fresh juices of these varieties. Franklin may be an exception, as the fresh juice in 1922 gave negative results for cane sugar.

The presence of cane sugar in those varieties in which it only occasionally occurs is in some degree, though not absolutely, correlated with immaturity. Nineteen hundred and twenty was a year of very unfavorable weather conditions during the ripening period—little rain but much cool, foggy weather. In Campbell Early, Catawba, Goethe, Isabella, Jefferson, King Philip, Lady, Noah, Rommel, Salem, Ulster, Vergennes, Wilder, and Worden the cane-sugar content found in 1920 was in each case the maximum found for the variety. In a number of these—Campbell Early, Goethe, King Philip, Rommel, Salem, Ulster, Vergennes and Wilder—the total sugar content is comparatively low as compared with other years. In Salem, Wilder, and Worden acid content is also high. In this group it would appear that unfavorable conditions for photosynthetic activity had resulted in low sugar content and had been accompanied by a partial failure of conversion of cane sugar into hexoses during the ripening period. On the other hand no cane sugar was found in Brilliant, Diamond, Elvira, Gaertner, Merrimac, and Woodruff, although all these varieties failed to develop full normal color or to mature properly, as is further indicated by their low total sugar content. To further complicate the case, 1923 was a year of unusually favorable seasonal conditions in which a number of varieties which occasionally fail to fully mature were able to do so, yet seven varieties (Brighton, Canada, Centennial, Delaware, Dutchess, Early Daisy, and Early Victor), unquestionably fully ripe, showed the presence of cane sugar in that year and at no other time, and the quantity present in a number of others (Agawam, Clinton, Concord, Dakota, "Dutchess Seedling," Eaton, Eumelan, Hartford, Ives, Lenoir, Niagara, and Pocklington) equaled or exceeded that found in other years. Consequently the presence of cane sugar can not be considered as positive proof of the immaturity of the fruit, as a larger number of varieties showed its presence under the exceptionally favorable conditions for ripening in 1923 than in any other year. Nor can it be definitely correlated with any other factor, such as temperature, insolation, water supply, or load of fruit on the vines.

### ACID CONTENT

Examination of Tables III and IV will at once show that varieties differ greatly in the amount of fluctuation in acid content occurring from year to year when grown side by side over a number of years. Thus Brighton, Brilliant, Canada, Diamond, Delaware, Eumelan, Herbemont, Lindley, Martha, Niagara, and Noah show a range of variation of less than 0.30 per cent during the period, while Agawam, Clevener, Diogenes, Isabella, Ives, Lenoir, Montefiore, and Norton have a range of 0.60 per cent or more. Yet both groups contain midseason and late-maturing varieties and neither can be said to have an advantage in adaptation to the soil or locality. The fact that the experimental period included exceptionally favorable and decidedly unfavorable years with intermediate conditions has probably resulted in the inclusion in the data of the extremes likely to be encountered in this particular region in a long period of years. Comparison with the data obtained by Alwood in the study of grapes from a number of States indicates that the fluctuation in acid content of a variety grown year after year in the same vineyard, even with very wide differences in seasonal conditions, are much narrower than those encountered in the same variety grown over a wide area with a diversity of soils and cultural conditions.

The extent to which variations in acid and sugar content in the grape are related has been the subject of considerable discussion in the European literature of wine making under the title of "Acid-sugar ratio." The value of a grape variety for wine making depends to a considerable degree upon this ratio, a high acid content resulting in a sour wine. Consequently varieties which were characterized by a fairly constant ratio, low in acid and high in sugar, were most desired, while those which showed widely fluctuating ratios or were high in acidity were less valuable. Alwood in his various publications has devoted some attention to the acid-sugar ratio in American grapes from the same point of view. Very little attention has been given to the question whether sugar and acid con-

tent in a given variety fluctuate entirely independently or with some degree of correlation. Müller-Thurgau (*48*) regarded the increase of sugar and reduction of acidity in ripening fruits not as inseparably related processes but as influenced by conditions such as temperature, water, and nutrient supply, leaf area, and size of crop on the vines, which influence the rate of metabolic processes. Kelhofer (*38*) published a graph summarizing the records for sugar and acid content of Raüchlings grapes for the 14 years 1891–1904, inclusive. Years of maximum acid content were also years of minimum acid content, and vice versa. Years of maximum sugar content for the period in a large number of varieties. These years were also characterized by minimum acid content for the period in a large number of varieties. On the other hand, 1922 and 1920 were years of low sugar content, very few varieties reaching their maximum or next to maximum sugar, and both years are characterized by the almost total absence of low acid readings and the large number of maximum or next to maximum figures found. Furthermore, 1921 is notable for the absence of either very high or very low figures for either constituent. The general conclusion to be drawn from the graph is that a

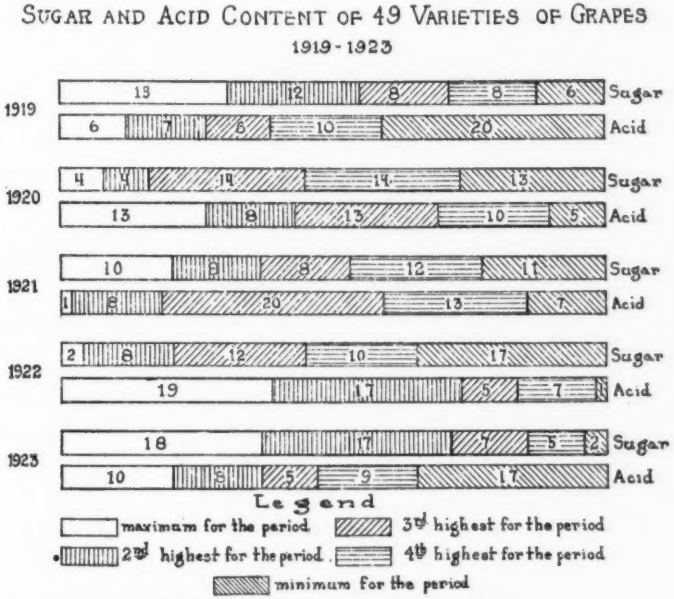


FIG. 1.—Sugar and acid content of grapes, 1919–1923

medium or average sugar content were years of medium acid content. No American studies upon this matter have been found in the literature. It is very important that the facts upon this point be known and understood, since the palatability of an unfermented juice, like that of a wine, depends in no small degree upon the sugar-acid ratio. The results of the present study, in so far as they bear upon the acid-sugar relation, are brought together graphically in Figure 1. From an inspection of the graph it will be immediately evident that 1923 and 1919 were years characterized by maximum or next to year of high sugar content is also one in which acidity is low, and conversely that a year which is markedly low in sugar content is one of more than average acidity. This is very clearly the general situation. There are a number of exceptions: Maximum acid and maximum sugar occur together in Catawba, Franklin, Herbemont, Isabella, Jefferson, and Noah in 1923, in Berckman and Cynthiana in 1922, in Goethe in 1921, and in Montefiore in 1919. Minimum sugar and minimum acid occur only in Dakota and Herbert in 1919 and in Lampasas and Martha in 1922. There are a large number of cases in

which maximum sugar and minimum acid occur together: Colerain, Concord, Dakota, Elvira, Perkins, Rommel, and Ulster in 1923; Brilliant, Goethe, and Niagara in 1921; Martha in 1920; and Clinton, Eumelan, Lindley, Massasoit, and Wilder in 1919. There are fewer instances of occurrence of minimum sugar and maximum acid together: Canada, Dutchess, Lenoir, Merrimac, and Montefiore in 1922, Barry in 1921, and Noah in 1919 make up the list. It is clear that there is no hard and fast connection between acid and sugar content in the grape, but rather a broadly general relationship. Conditions which favor the production of a crop of high sugar content also favor the reduction of acidity to a low level; conditions which depress the sugar production also tend to maintain acidity at a high level. This point will receive further discussion in a subsequent section.

The maximum and minimum acid-sugar ratios occurring in each of 49 varieties during the five years are tabulated in Table V. There is added for purposes of comparison an average acid-sugar ratio for each variety obtained by taking the mean of the yearly ratio for five years. By reason of the fact that the experimental period contained exceptionally unfavorable as well as unusually favorable crop years, the results probably present as wide variations as would be encountered at Vineland in a long series of years. Owing to the inclusion of the unfavorable seasons and differences in the methods of sampling the fruit and expressing the juice, and for perhaps other reasons, the average acid-sugar ratios differ materially from those reported by Alwood. The differences are all in the direction of a higher ratio of acid to sugar, as would be anticipated from the inclusion of two years characterized by low sugar and high acid content.

The varieties studied may be grouped into three groups on the basis of their average acid-sugar ratios. These are a high acid group, consisting of juices whose proportion of acid to sugar is so high as to make them too sharp for beverage use; a balanced or medium group, in which the proportions are such as make the fresh juice agreeable and palatable; and a subacid group, in which the acid content is so low as to make the juice too insipidly sweet to be acceptable as a beverage.

The definition of the exact limits of these groups is a matter of some difficulty. At present Concord is practically the only generally available, commercial grape juice, and it is logical to assume that its acid-sugar ratio is that which most people find agreeable and properly balanced, else it could not have attained its present popularity. It may therefore be made to serve as a starting point in a classification of juices with respect to beverage quality. Hartmann and Tolman (*27*) collected and analyzed 104 hot-pressed commercial Concord grape juices representing the principal producing districts. Their analyses may be assumed to fairly represent the juices available in the markets. The average sugar content for the 104 samples was 15.31 per cent, the average total acidity calculated as tartaric was 1.01 per cent, giving an acid-sugar ratio of 1:15.1. The maximum ratio found was 1:10.7, in a sample having 11.66 per cent of sugar and 1.09 per cent acid. The minimum was 1:19 in a sample

TABLE V.—*Maximum and minimum acid-sugar ratio*

| | Maximum | Minimum | Average |
|---|---|---|---|
| Agawam | 1:12.1 | 1:22.5 | 1:17.8 |
| Barry | 1: 9.7 | 1:16.2 | 1:12.5 |
| Berckman | 1:12.1 | 1:15.5 | 1:13.6 |
| Brighton | 1:23.8 | 1:40.5 | 1:29.4 |
| Brilliant | 1:18.8 | 1:31.4 | 1:25.4 |
| Canada[1] | 1:11.2 | 1:18.3 | 1:15.7 |
| Catawba | 1:15.3 | 1:22.4 | 1:16.1 |
| Clinton | 1:10.2 | 1:14.7 | 1:11.9 |
| Clevener | 1: 6.2 | 1:10.8 | 1: 8.9 |
| Colerain | 1:13.6 | 1:26.2 | 1:20.0 |
| Concord | 1:10.9 | 1:19.8 | 1:15.7 |
| Cynthiana | 1:10.2 | 1:14.8 | 1:13.5 |
| Dakota | 1:10.0 | 1:15.6 | 1:12.2 |
| Diamond | 1:11.9 | 1:18.2 | 1:15.1 |
| Diana | 1:16.7 | 1:24.7 | 1:19.7 |
| Diogenes | 1: 8.2 | 1:16.0 | 1:11.2 |
| Delaware | 1:20.5 | 1:32.8 | 1:24.8 |
| Dutchess | 1:16.4 | 1:32.3 | 1:24.8 |
| Elvira | 1:11.5 | 1:19.2 | 1:14.6 |
| Eumelan | 1:23.7 | 1:41.7 | 1:29.4 |
| Franklin | 1: 7.5 | 1:11.7 | 1: 9.5 |
| Goethe | 1:14.6 | 1:20.9 | 1:17.3 |
| Herbemont | 1:11.7 | 1:13.6 | 1:12.7 |
| Herbert | 1:14.6 | 1:21.1 | 1:17.9 |
| Isabella | 1:13.9 | 1:21.3 | 1:16.7 |
| Ives | 1: 9.1 | 1:28.0 | 1:19.1 |
| Jefferson | 1:16.4 | 1:24.4 | 1:20.2 |
| Lampasas | 1:15.3 | 1:23.6 | 1:19.6 |
| Lenoir | 1: 6.6 | 1:11.4 | 1: 9.5 |
| Lindley | 1:21.1 | 1:37.1 | 1:25.6 |
| Lucile | 1:18.4 | 1:29.1 | 1:22.2 |
| Martha | 1:25.8 | 1:34.7 | 1:30.9 |
| Massasoit | 1:12.5 | 1:25.7 | 1:18.9 |
| Merrimac | 1:14.9 | 1:23.3 | 1:19.7 |
| Missouri Riesling | 1:13.7 | 1:17.8 | 1:16.2 |
| Montefiore | 1:14.4 | 1:31.9 | 1:23.7 |
| Nectar | 1:10.9 | 1:24.2 | 1:18.1 |
| Niagara | 1:21.6 | 1:28.0 | 1:23.9 |
| Noah | 1:11.0 | 1:16.6 | 1:14.5 |
| Norton | 1:10.6 | 1:17.6 | 1:14.4 |
| Perkins | 1:14.8 | 1:26.0 | 1:19.7 |
| Pocklington | 1:12.0 | 1:23.6 | 1:19.5 |
| Rommel | 1:13.9 | 1:22.0 | 1:17.4 |
| Salem | 1:15.4 | 1:27.6 | 1:21.0 |
| Ulster | 1:15.8 | 1:26.7 | 1:20.2 |
| Vergennes | 1:17.1 | 1:25.5 | 1:20.5 |
| Wilder | 1:11.5 | 1:35.1 | 1:20.8 |
| Woodruff | 1:17.9 | 1:24.1 | 1:20.7 |
| Worden | 1:10.7 | 1:25.6 | 1:15.8 |

with 17.31 per cent sugar and 0.91 per cent acid. With these exceptions, the juices studied by Hartmann and Tolman had ratios between 1:12.5 and 1:17.5, with 1:15 as the mean. If Hartmann and Tolman's results are fairly representative of commercial Concord grape juice, as their number and distribution would indicate, it may be assumed that the public finds juices having such a range in acid-sugar ratios acceptable for beverage purposes in so far as these constituents are concerned, while those above or below these limits fall into the high acid and subacid groups, respectively. Of course, the palatability of a juice does not depend wholly upon the acid-sugar ratio, but this is a factor of outstanding importance.

Carrying out the arrangement of the varieties into groups upon this basis, we have the three groups constituted as follows:

HIGH-ACID GROUP (acid-sugar ratio 1:12 or higher): Barry, Clinton, Clevener, Cynthiana, Dakota, Diogenes, Franklin, Herbemont, and Lenoir.

MEDIUM OR BALANCED GROUP (acid-sugar ratio about 1:15): Berckman, Canada, Catawba, Concord, Diamond, Elvira, Goethe, Isabella, Ives, Missouri Riesling, Nectar, Noah, Norton, and Worden.

SUBACID GROUP (acid-sugar ratio 1:17.5 or less): Agawam, Brighton, Brilliant, Colerain, Diana, Delaware, Dutchess, Eumelan, Herbert, Jefferson, Lampasas, Lindley, Lucile, Martha, Massasoit, Merrimac, Montefiore, Niagara, Perkins, Pocklington, Salem, Ulster, Vergennes, Wilder, and Woodruff.

Some varieties do not fit very closely into this classification because of variations in acid-sugar ratio which are considerably wider than the limits of any one group. Examples are Agawam, Barry, Colerain, Diogenes, Ives, and Wilder. These are varieties which show a wide variation in acid or in sugar content or both, as may be seen by reference to the analytical data in Table III, with the result that the ratio in some years stands apart from the others. Such varieties have been placed in the groups to which the results for the remaining years, together with the average, would place them. Canada, Montefiore, and Perkins in one year (1922) had crops of very high acidity and minimum sugar with resulting ratios materially higher than for other years. The very unfavorable weather conditions prevailing during the ripening period in 1922 affected several other late-maturing varieties in the same way. The widest variations in ratio are found in the subacid group, Brighton, Brilliant, Eumelan, Lindley, and Wilder showing especially wide ranges. Two varieties, Noah and Norton, stand on the border line between the high-acid and the balanced groups.

Broadly speaking, the fact that the acid-sugar ratio is as constant as the figures show it to be when the crops were produced under the variety of seasonal conditions encountered at Vineland in 1919–1923 shows conclusively that knowledge as to the ratio for a variety is of material assistance in indicating its possibilities as a source of beverage juice.

## TOTAL ASTRINGENCY, OR TANNIN, CONTENT

The suitability of a fruit juice for beverage purposes depends not only upon the amounts of sugar and acid it contains but also upon the amounts of astringent constituents present. A palatable beverage juice must have a certain fairly definite balance or proportion between the three constituents—sugar, acid, and tannin. If the tannin is deficient in amount the juice will be lacking in sprightliness and agreeable aftertaste; if it be in excess the juice will be harsh and astringent with a suggestion of bitterness. The insipid character of the juices of many of our choicest table varieties of grapes and the harshness and lack of palatability of the juices of most wild grapes are instances of these extremes, while Concord juice is an example of a fairly well balanced juice. The amount of astringent material present is as important as the sugar-acid ratio in determining the value of a grape juice for beverage purposes.

While a considerable number of methods for the determination of total astringency and astringent nontannins in fruit juices have been proposed, none of them has displaced the Loewenthal-Proctor method, which remains essentially as described by Neubauer in 1872 (*50*) with the difference that powdered kaolin is substituted for bone black in filtering off the gelatin-tannin precipitate. For quantitative purposes this method is faulty in several respects. The chief defect is that all substances which reduce $KMnO_4$ are included in readings as tannins, either wholly or in part. The products of the reaction of tannin with gelatin are variable and the precipitation is a colloidal one which varies with conditions, as Wood (*62*) has shown. The filtration of the tannin-gelatin precipitate with kaolin involves a variable error, since the red pigment of some deeply colored juices is very strongly adsorbed by the filter paper used and can not be wholly re-

moved by prolonged washing with water. The calculation of the non-tannin astringency to grams per 1,000 c. c. by the use of the factor used for tannin, involves a large error, as the substances making up the astringent nontannins are highly diverse in character. It has been known since the work of Neubauer (*50*) in 1872 that the pigment of a certain red wine, studied by him, when prepared in a fairly pure state, had only 30 per cent the reducing power of pure tannin (0.00754 gram of Neubauer's preparation equalled 0.002296 gram tannin in reducing power for $KMnO_4$), while Kelhofer (*39*) found that when he titrated purified pear tannin with $KMnO_4$ the results indicated only 64 per cent of the weight of tannin actually employed in the determinations. For these reasons the results obtained when the method is employed for a large number of juices which vary considerably in nature and amount of coloring matter and other oxidizable nontannins present are at best only roughly comparative.

A study of the literature on methods of determination of tannin in fruit juices was undertaken in the hope that a method could be found which would differentiate somewhat more accurately between tannins and nontannins and which could be used in work with fresh juices under rather primitive field conditions. A review of the summaries by Nierenstein (*51*, *52*) and Czapek (*18*), and of the work of Spiers (*55*), Laborde (*41*), Fresenius, and Grünhut (*22*), Meyer (*47*), and others indicated that there is no method which can be depended upon for quantitative results which can be used in field work. Since the results reported in the literature are expressed in terms of the Loewenthal-Schroeder method as modified by Proctor, its employment would permit direct comparison of results and it was therefore employed for the field work. Another consideration which led to the abandonment of any attempt to obtain anything more than roughly comparative results upon the fresh juices is the very large and rapid change in soluble astringent constituents which freshly pressed juices undergo upon exposure to the air. As a consequence of this alteration, which has been recorded by Lindet (*43*), Hotter (*32*, *33*), and studied especially by Kelhofer (*35*, *36*, *37*, *39*), the tannin content of a freshly pressed fruit juice is a maximum which decreases as the juice passes through the processes of bottling and pasteurization to reach a stationary point sometime after pasteurization. Therefore such determinations do not give any indication as to the degree of astringency a given juice will possess when it reaches the consumer, if prepared in the usual way. Their chief interest is through the indications such determinations may give as to the nature and extent of the effect of seasonal conditions upon the content of astringent constituents. It is a fact of considerable practical significance that juices which have been clarified by filtration with diatomaceous earth by the methods described by the writer (*17*), do not undergo loss of astringency upon pasteurization. This method of filtration therefore has the merit, not fully appreciated when the paper referred to was prepared for publication, that it not only gives permanently clear filtrates but that it also preserves the juices from subsequent alteration in their sugar-acid-tannin ratios. A detailed study of the chemical changes in apple and grape juices as a result of pasteurization is now being made as one phase of the investigations upon fruit juices in progress in this laboratory and will be published separately. A discussion of the effects of diatomaceous earth filtration as related to pasteurization will be included in that paper, reference being made here by reason of its practical importance.

Tannin determinations upon fresh juices were not made in 1919 and 1920, so comparisons for only three seasons are possible. The data obtained in 1921, 1922, and 1923 are presented in Table III.

There are in the literature very few similar determinations with which comparisons may be made. Hartmann and Tolman determined tannin and coloring matter in the series of Concord juices studied by them, but these were hot-pressed juices, and the determinations were made after pasteurization, and hence are not comparable. Noyes, King, and Martsolf (*53*) made tannin determinations on Concord grapes throughout the harvest period, and Alwood and his collaborators (*2*) made similar determinations in their studies of ripening in Catawba, Clinton, Delaware, Ives, Norton, and Concord. The results in both these pieces of work indicate that the tannin and coloring matter fluctuate very irregularly throughout the ripening and harvest period, without definitely increasing or decreasing after the berries have begun to color. Tannin determi-

nations were not made by Alwood in his more extensive studies of grapes from the eastern districts, so his results give no information as to the variation in these constituents from year to year or when grown in various localities.

The outstanding fact brought out by the determinations of astringency is that there is very considerable fluctuation in total astringency in all varieties. Cynthiana, Franklin, Martha, Norton, and Wilder being exceptional in that they are comparatively constant. 1923 was a year of notably low total astringency, 42 varieties showing the minimum amounts while only two, Clevener and Wilder, had their highest astringency. 1922 was a year of markedly general high astringency, 35 varieties showing the maximum for the period in that year, while only four varieties—Catawba, Clevener, Diogenes, and Franklin—had their minimum. 1921 occupied an intermediate position, 11 varieties showing maximum, while only three—Isabella, Lampasas, and Wilder—have the minimum.

While the records of the total astringency at pressing cover only three years and are therefore insufficient to warrant extended generalizations, it may be pointed out that the results show a parallelism with the acid determinations. The comparisons for acidity cover five years' results, those for astringency only three, but the tendency to fluctuate together is clear. 1923 was a year characterized by minimum or next-to-minimum acid content in more than half the varieties, while more than four-fifths show the minimum in total astringency. 1922 was a year of high acidity, 36 varieties out of 49 showing maximum or next-to-maximum acid content for the five-year period, while 35 had the maximum total astringency encountered in the three-year period. In 1921 the acidity for the great majority of varieties was intermediate, few varieties appearing at either extreme, while 32 have total astringency figures intermediate between those of 1922 and 1923.

As might be anticipated when the diversity of the substances determined as astringent nontannins is considered, the part contributed by these to the total astringency reading fluctuates considerably from year to year in most varieties. Contrary to expectation, the fluctuations in nontannin astringency found in white varieties, such as Colerain, Diamond, Dutchess, Elvira, Niagara, Noah, and Pocklington, are proportionately as wide as those in heavily pigmented varieties, though the absolute amounts are considerably smaller. Broadly speaking, total astringency and true tannins rise or fall together, 33 varieties having maximum tannin in 1922, while 20 had minimum tannin in 1923. Twenty-seven had maximum astringent nontannins in 1922, while 44 had minimum astringent nontannins in 1923, so it seems that the amount of these constituents rises or falls with the total astringency but not necessarily to the same degree. While determinations for a 3-year period do not warrant dogmatic conclusions, it would appear from the data that there is a considerable degree of correlation between acidity, total astringency, and tannins and astringent nontannins, and that all these factors respond to seasonal conditions in like manner but in varying degree.

## CLIMATIC CONDITIONS AT VINELAND FOR PERIOD OF EXPERIMENT

The Weather Bureau has maintained a station in Vineland since 1868, and the data as to rainfall, sunshine, and temperature for the period have been taken from the published reports for that station in Climatological Data: New Jersey section for the years 1917–1923, inclusive. More detailed records of the stations at Trenton and Atlantic City, N. J., and Philadelphia, Pa., as published in the Monthly Meteorological Summary, Form No. 1030, by each of these stations, have been furnished through the kindness of the meterologists of these stations; and a transcript of the record kept at Wilmington, Del., was supplied by the street commissioner of that city. Comparative study of the detailed records at these stations has been of assistance in interpreting the less detailed Vineland records.

The first four years of the period covered by the work has been characterized by the meterologist for New Jersey (*60*) in the following words:

> In the State, as a whole, there has been from the year 1917 to date (November, 1922) a steadily increasing deficiency of precipitation. The years 1919 and 1920 were slightly above normal in precipitation, but all the other years, or almost any one of them, more than made up for those two years of excess. The lack of water supply, then, must be attributed to more than the deficient rainfall of the past few months.

This statement might with equal truth have been written a year later, and with specific reference to condi-

tions at Vineland, as the rainfall record at the end of November, 1923, for that station stands as follows:

| | Inches. |
|---|---|
| Deficiency for 1917 | −5.10 |
| Deficiency for 1918 | −7.94 |
| Excess for 1919 | 12.61 |
| Deficiency for 1920 | −.44 |
| Deficiency for 1921 | −10.07 |
| Deficiency for 1922 | −.86 |
| Deficiency for 11 months of 1923 | −3.96 |
| Accumulated deficiency [10] | 15.76 |

The progressive accumulation of a deficiency of this amount had a progressively increasing effect upon the ground water level, as was evidenced in the last three years of the work by the failure during the summer and autumn months of many of the shallow wells in the vicinity of the vineyard. Water is usually obtained everywhere in the area by wells driven to a depth of 15 to 25 feet, but many of the shallow wells failed entirely in the autumn of 1921 and yielded considerably reduced supplies in 1922 and 1923.

The year 1917 was characterized by an average mean temperature 1.9° below the 49-year average, the mean temperature for the separate months exceeding the average only in January, March, April, and August. May was markedly cool, 5.7° below the average; June and July were normal; August 1.6° above normal; and the remaining months of the year 3.1°, 2.6°, 1.9°, and 5.4° below the average.

The rainfall, while only 5.10 inches below the average annual precipitation, was so distributed as to result in a degree of drought during the growing season which affected the yields of many crops. An excess of 2.52 inches in March did not make up the shortage for the preceding months, there was a deficiency of 1.55 inches in May, 3.94 inches in August, and 0.93 inch in September, the other summer months showing normal or a few hundredths more than normal precipitation. An excess of 5.26 inches in October fell mainly toward the end of the month, too late to directly affect crops. The six "growing months," April to September, inclusive, received 6.10 inches less than the normal precipitation for the period, so that the grape crop was grown with a material shortage of water and ripened in a period of abnormally cool dry weather.

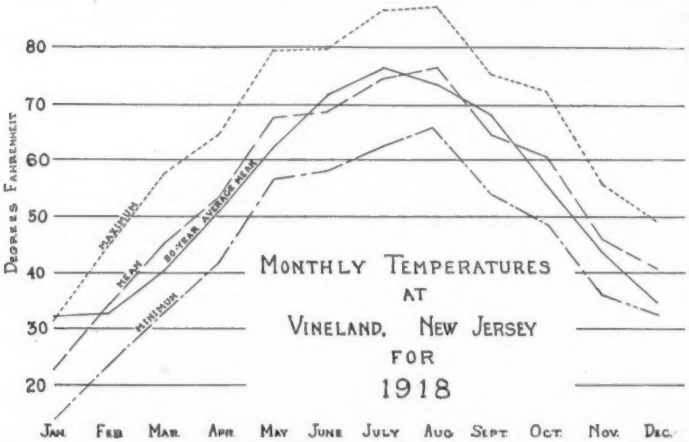


FIG. 2.—Maximum, minimum, and mean monthly temperatures at Vineland, N. J., in 1918, with average mean temperature for 49-year period for comparison

## CLIMATIC RECORD FOR 1918

The climatic conditions for 1918 are graphically presented in Figures 2 and 3. Figures showing percentages of possible sunshine at Vineland are not published separately, but a record of days classified as "clear" (having 0 to 30 per cent of cloudiness during hours of possible sunshine), "partly cloudy" (having 40 to 70 per cent of cloudiness), and "cloudy" (having 80 to 100 per cent of cloudiness) is kept, and these data

[10] These figures represent a close approximation rather than an exact statement, for the reason that the rainfall records for Vineland are incomplete or missing for March, 1917, September, 1918, March, 1919, July and August, 1920, and February, 1922. Figures for the stations at Bridgeton, 12½ miles southwest of Vineland, and Hammonton, 17 miles northeast, have been supplied for the missing months, as the rainfall at these stations closely approximates that occurring at Vineland.

are presented in Figure 3. The detailed data from the adjacent stations at Atlantic City, Philadelphia, and Trenton have been examined, and some general facts adduced therefrom are stated in the subsequent discussions, but the graphs representing sunshine are based on the Vineland data alone. The mean temperature records show that January was a month of exceptionally low temperatures, the coldest on record in the State. From February on through May the mean was consistently well above the average, the last killing frost occurring on May 7. June, July, and September were slightly below, August somewhat above normal, light showers until mid-July, when a period of extreme heat and drought set in. This was broken by rainfall of 6.36 inches on July 31. August was extremely hot with only one wetting rain (0.64 inch) on the 15th. This somewhat accelerated the maturing of the crop. The normal rainfall and cooler weather of September, followed by drought and heat through October, permitted normal ripening of a crop of slightly less than average size. November was mild, dry, and warm, the first killing frost occurring on the 7th, and December was normal in rainfall but exceptionally warm and without snow. The year was one which was

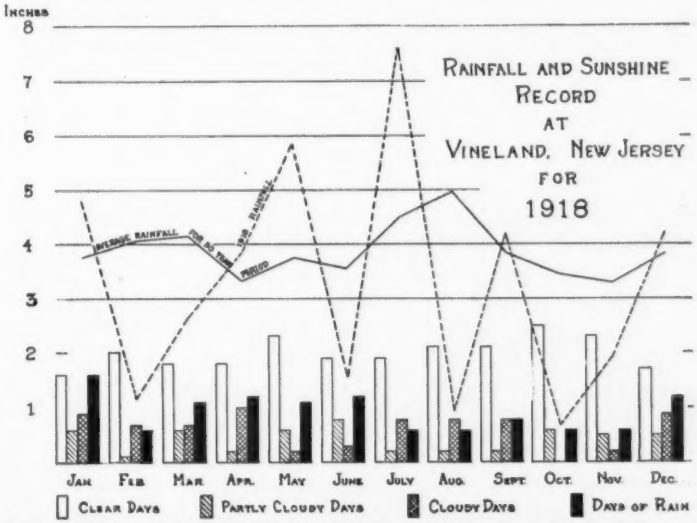


FIG. 3.—Rainfall and sunshine at Vineland, N. J., in 1918, with 49-year average for comparison. (All days on which a trace, 0.01 inch or less, was recorded are included; hence, some days recorded as clear are also included under days of rainfall)

and warm mild weather was continuous from October 1 through the remainder of the year, the first killing frost occurring on November 7.

The outstanding features of the precipitation for the year was its marked deficiency (7.94 inches), its irregular distribution, and the infrequency of prolonged periods of cloudy, showery weather. The vines began to grow early in the season and the conditions during the blooming period were favorable to the setting of a crop of fruit of normal size on almost all varieties. Pollination of a few varieties was somewhat interfered with by rain on May 9. The low rainfall of June was accompanied by cool weather with occasional considerably deficient in soil moisture throughout the growing season but which supplied conditions for maximum photosynthetic activity through an unusual percentage of sunshine well distributed over the entire growing season. That this characterization of the condition for photosynthesis is justified will be at once evident from a comparison of Figure 3, showing number of clear days per month, with the graphs presenting like data for subsequent years. The seven months, March to September, inclusive, which cover the period from resumption of growth to maturity of the fruit, had 18 to 23 days each which were reported as clear, a total of 141 days for the seven months.

This indicates a degree of freedom from prolonged periods of cloudy, showery weather and fogs, quite exceptional for spring and summer at Vineland.

This statement of the crop conditions for the two years preceding the beginning of the chemical studies may serve as a background for that work and assist in the interpretation of the data obtained in subsequent years.

### Climatic Record for 1919

The outstanding features of the year 1919 are the mildness of the winter, the consistently above normal mean temperatures from January to June and from October to the end of the year (fig. 4), the large excess of precipitation (12.61 inches) over the average, and the occurrence of almost one-fourth of the total rainfall in July and August (fig. 5).

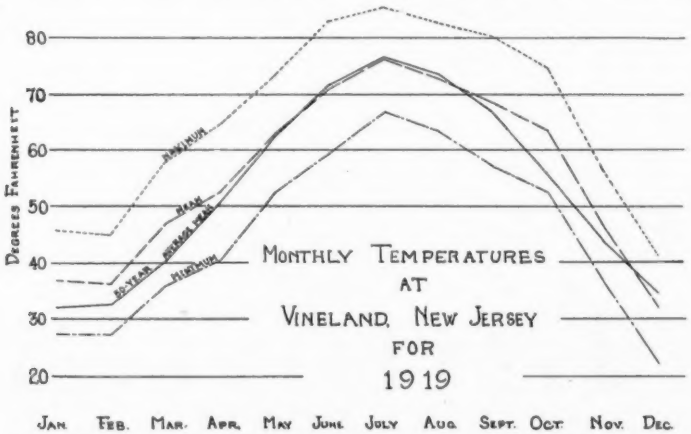


Fig. 4.—Maximum, minimum, and mean temperatures in 1919 at Vineland, N. J., with 50-year average mean for comparison

Rainfall was slightly below normal for the winter and spring months but was excessive in May, which had three weeks of almost constantly cloudy, warm weather with rain on 13 days, 3.47 inches being recorded on the 10th. June was normal in temperature and sunshine but deficient in rainfall. July and August were marked by almost continuous cloudiness. From July 6 to 24 there were 14 days when it rained. August had 11 days rain. A heavy gale of wind, accompanied by 5.61 inches of rain, on August 14 did considerable damage to vines and fruit. The total rainfall for the two months, 13.97 inches, was 4.59 inches in excess of the normal, and the low sunshine for the whole period was unfavorable to the crop. Ripening of the earlier varieties was considerably retarded by cool, cloudy weather, with light showers during the first half of September, after which warm dry weather, which extended with increasingly abnormal high temperature through October resulted in rather rapid ripening. November was dry and warm, the first killing frost occurring on the 9th, and December was unusually cold, with more than the usual amount of snow.

To sum up the climatic conditions for 1919 as they are related to the production of the crop, the deficiency in soil moisture carried over from 1918 was continued until July, when the crop was well advanced, and was not wholly made up until the middle of August. The period June to September was one of practically normal mean temperatures and normal percentages of possible sunshine, while the early spring months and the ripening period had a slight excess of both temperature and sunshine. As the vines bore a slightly smaller crop than usual, it would be a justifiable presumption that the fruit would show no marked departures from normal in its composition. The data for clear, partly cloudy, and cloudy days presented in Figure 5 show that the whole period of development and maturity of the crop was characterized by a predominance of clear, sunshiny days, varying in number from 18 to 22 per month. In number of clear days during these

months, 1919 is first of the five years during which sampling of the crop was carried on.

### Climatic Record for 1920

The unusually cold weather of December, 1919, continued through January, 1920, but abated somewhat in February. The spring months were slightly above normal, July almost 3° below normal, and all the subsequent months of the year 1 to 5° above the 50-year average (fig. 6). The last killing frost of the spring occurred May 6, but the damage done to grapes was very slight. The rainfall for the year was 0.44 inch less than normal—but was abnormal in distribution—the winter and early spring months having a little less than usual, with an excess of 4 inches in June, a deficiency of 80 per cent in October, and an excess in November and December. It is evident from inspection of Figure 7, in comparison with Figures 3 and 5, that the percentage of sunshine in the growing months of 1920 was considerably less than that for the same period in 1918 and 1919. Such comparison is facilitated by reference to Table VI, which presents the data for six years, 1918–1923, for the period March–September, inclusive.[11] The number of clear days reported for this period in 1918 and 1919 was 141 and 134, respectively, as against 110 for 1920 (fig. 7), or, expressed as percentages of the total number of days in the period, the clear days were 65.8, 62.6, and 51.26 per cent of the possible for the three years 1918, 1919, and 1920. The differences between 1919 and 1920 are great enough to be of considerable significance in determining the amount of photosynthetic activity for the season. To arrive at any accurate comparison however, the days recorded as partly cloudy must also be evaluated. The term "partly cloudy," as used in the weather reports, is applied to any day which has 40 to 70 per cent of its possible sunshine prevented by clouds. For comparative purposes, some value must be assigned to these days, as soon as photosynthetic activity occurred thereon. If we arbitrarily assume that where large numbers are concerned, partly cloudy days have on the average 50 per cent of sunshine, and add to the number of clear days one-half the number of

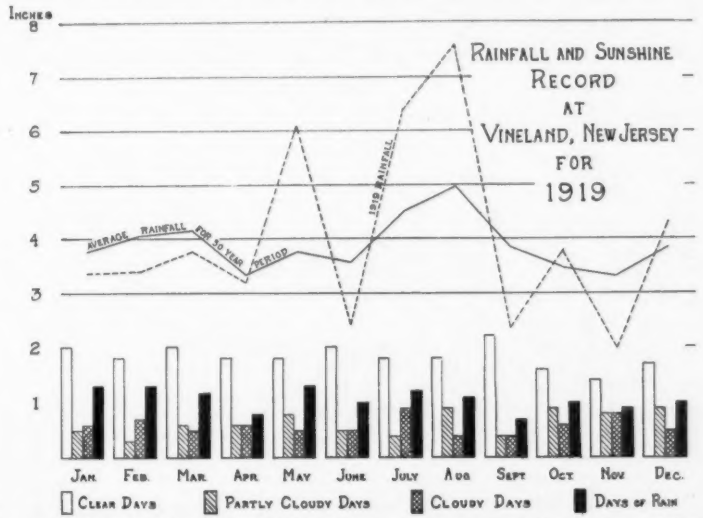


Fig. 5.—Rainfall and sunshine at Vineland, N. J., in 1919, with 50-year average for comparison. (All days showing a trace, 0.1 inch or less, are included. Some inconsistencies will be noted in the graph, the days of rain plus the number of clear days in some instances exceeding by one or two the number of days in the month. In some instances this is due to incompleteness of the Vineland records, necessitating substitution of data from the nearest station; in others to inconsistency in the Vineland records themselves as, days on which a trace of rain fell were reported as being clear)

[11] This period is chosen for comparative purposes for the reason that grape harvest is well advanced and often practically complete by the end of September, only a few late maturing varieties remaining to be gathered after October 1 in normal seasons.

recorded as partly cloudy, we have 158, 155, and 145 days of the 214-day period as days of sunshine in the three years. Expressed as percentages, these equal 73.8, 72.4, and 67.7 per cent of the total number of days in the period. It must be emphasized that in making this comparison an arbitrary valuation has been assigned to the sunshiny hours of partly cloudy days, and that the figures arrived at must not be regarded as exact mathematical statements of what occurred in the three seasons in question. It is clear from the data in Table VI, however, that for the period covered by this work the year 1920 had the smallest number of clear days and the largest number of partly cloudy or wholly cloudy days during the growing season, and that consequently the sunshine received was minimum in amount as compared with the other years of the period. While the fruit of most of the varieties remained on the vines a week to two weeks after the end of September, the season being exceptionally late, this did not materially increase the amount of sunshine received for a reason stated in the next paragraph.

The situation which actually existed during the period September 15 to October 15 is not indicated by the monthly summary of weather data in the graph. The period September 13 to 23 was rainless, and ripening of the earlier varieties proceeded normally. A period of cloudy, sunless weather began on the 24th and continued through the remainder of the month, more than three-fourths of the precipitation for the month occurring on the 26th, 28th, and 29th. While the only precipitation in October occurred on the 28th the period between the 1st and 16th was remarkable for the nightly dense fogs which usually persisted till midafternoon and broke away to recur shortly after nightfall. The temperatures during the nights and forenoons were low, and though there were short periods of sunshine in the afternoon during which a fairly high maximum was attained the ripening of the fruit was slowed down greatly and some varieties did not reach normal coloration. The harvest extended from September 18 to October 17, at least a week longer than in any other year.

The persistence of warm weather through November delayed the appearance of killing frost until November 12. There was an excess of rainfall in both November and December with total absence of snow and the usual December temperatures.

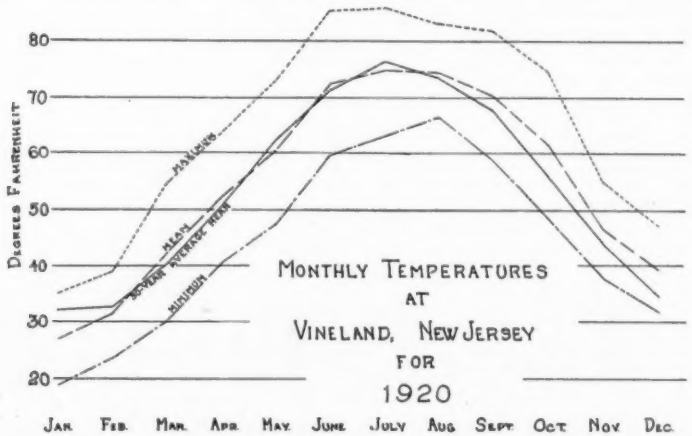


FIG. 6.—Maximum, minimum, and mean temperatures at Vineland, N. J., in 1920, with 50-year average for comparison

## CLIMATIC RECORD FOR 1921

The outstanding features of the climatic record for 1921 are the almost total absence of typical New Jersey winter weather and the great deficiency of precipitation throughout the State (10.07 inches at Vineland) (figs. 8 and 9). The mean temperatures at Vineland for the four months January to April, inclusive, were 4.6°, 5.4°, 14.4°, and 8.6°, respectively, above the 50-year average, the minimum temperature recorded in March being 1.7° above the normal mean temperature for the month. This highly abnormal

condition hastened the development of vegetation, with disastrous results to the grape crop. A cold wave of several days duration at the end of March was accompanied by heavy frosts and temperatures of 24° on March 29 and 27° March 30 and April 2. The youngshoots on most varieties were at that time 4 to 10 inches long, with the blossom clusters showing plainly on the earlier-blooming varieties. All were killed. On April 11 and 12 a

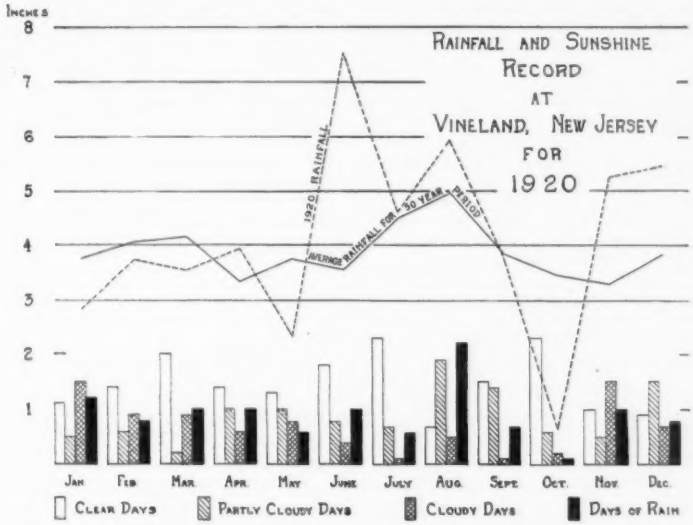


FIG. 7.—Rainfall and sunshine at Vineland, N. J., in 1920, with 50-year average for comparison. (All days on which a trace, 0.1 inch or less, was recorded are included)

TABLE VI.—*Number of days recorded as "clear," "partly cloudy," and "cloudy" at Vineland, March to September, inclusive, 1918 to 1923, inclusive*

| | March | April | May | June | July | August | September | Number | Percentages |
|---|---|---|---|---|---|---|---|---|---|
| 1918: | | | | | | | | | |
| Clear | 18 | 18 | 23 | 19 | 21 | 21 | 21 | 141 | 65.8 |
| Partly cloudy | 6 | 2 | 6 | 8 | 6 | 2 | 2 | 32 | 15.0 |
| Cloudy | 7 | 10 | 2 | 3 | 4 | 8 | 7 | 41 | 19.1 |
| 1919: | | | | | | | | | |
| Clear | 20 | 18 | 18 | 20 | 18 | 18 | 22 | 134 | 62.6 |
| Partly cloudy | 6 | 6 | 8 | 5 | 4 | 9 | 4 | 42 | 19.65 |
| Cloudy | 5 | 6 | 5 | 5 | 9 | 4 | 4 | 38 | 17.75 |
| 1920: | | | | | | | | | |
| Clear | 20 | 14 | 13 | 18 | 23 | 7 | 15 | 110 | 51.26 |
| Partly cloudy | 2 | 10 | 10 | 8 | 7 | 19 | 14 | 70 | 32.7 |
| Cloudy | 9 | 6 | 8 | 4 | 1 | 5 | 1 | 34 | 16.0 |
| 1921: | | | | | | | | | |
| Clear | 19 | 14 | 14 | 17 | 18 | 22 | 15 | 119 | 55.6 |
| Partly cloudy | 9 | 7 | 8 | 10 | 9 | 3 | 8 | 54 | 25.2 |
| Cloudy | 3 | 9 | 9 | 3 | 4 | 6 | 7 | 41 | 19.1 |
| 1922: | | | | | | | | | |
| Clear | 14 | 18 | 19 | 11 | 19 | 12 | 21 | 114 | 53.2 |
| Partly cloudy | 6 | 5 | 6 | 10 | 10 | 10 | 3 | 50 | 23.36 |
| Cloudy | 11 | 7 | 6 | 9 | 2 | 9 | 6 | 50 | 23.36 |
| 1923: | | | | | | | | | |
| Clear | 16 | 19 | 21 | 21 | 12 | 16 | 15 | 120 | 56 |
| Partly cloudy | 8 | 4 | 6 | 7 | 15 | 10 | 10 | 60 | 28 |
| Cloudy | 7 | 7 | 4 | 2 | 4 | 5 | 5 | 34 | 16 |

Percentage of possible clear days: 1918, 73.36, or 158; 1919, 72.45, or 155; 1920, 67.75, or 145; 1921, 68.22, o 1146; 1922, 64.95, or 139; 1923, 70.09, or 150.

minimum temperature of 29° was recorded at Vineland. This completed the destruction of the flowering shoots on all except a few varieties in which growth had not advanced far. Thirteen varieties—Agawam, Cynthiana, Franklin, Hartford, Herbemont, Iona, Lenoir, Missouri Riesling, Noah, Norton, "Seibel Hybrid No. 2," Vergennes, and Wilder—suffered little or no apparent injury. With all other varieties there was either entire failure to fruit or considerably smaller than normal crops from buds which were dormant at the time of the freeze (*9*). Unfortunately it was not possible to visit the vineyard at the time of the freeze, so the only information available on the effects of the freeze is that given by the owner and his employees, two of whom were thoroughly familiar with the vineyard through continuous employment therein from the time it was planted. Their statements agree that in practically all varieties two to three weeks were required for development of new growth to the point it had reached at the time of the freeze.

Data on the yield of the various varieties were obtained in detail at the time of harvesting the crop, as it was recognized that reduced yields might materially affect the chemical composition of the crop. This data is presented as percentages of normal crop in Tables III and IV.

The precipitation for the year was very markedly deficient. The winter months were dry. Rainfall equaled the normal in March and very slightly exceeded it in April, after which it remained below normal until the close of the growing season. The months of April to October received only 18.44 inches of rainfall as compared with the normal 27.01 inches for this period, so that the whole period of development and ripening of the crop was marked by a steadily increasing deficiency of water. Severe drought conditions developing in July were partially relieved by the August rains, which were 86.6 per cent of the normal, but drought again became severe in September and October.

The mean temperature, after dropping to normal in May, rose again in June and July considerably above the average, dropping slightly below normal in August, then remaining above normal for the remainder of the year.

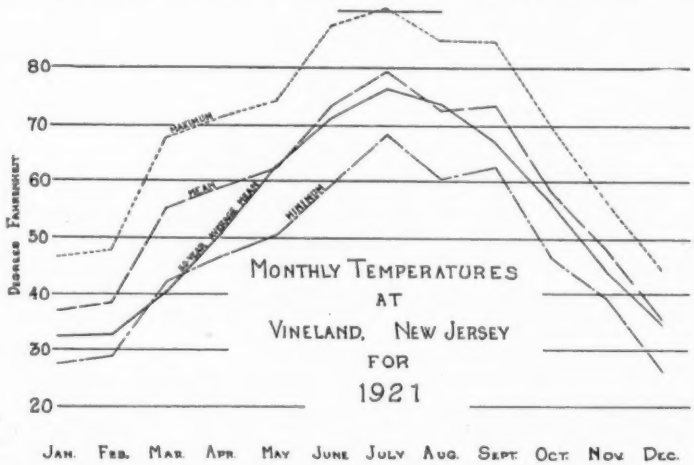


FIG. 8.—Maximum, minimum, and mean monthly temperatures in 1921 at Vineland, N. J., with a 50-year average for comparison

The number of days reported as clear in the months March to September, inclusive, was 119, or 55.6 per cent of the total, as against 110 clear days, or 51.26 per cent of the total, for the year 1920. If we repeat the assumption made in the discussion of the 1920 conditions, that one-half the time reported as "partly cloudy" days be considered as clear, we have 27 additional days, making a total of 146, or 68.2 per cent of the growing period. This is practically identical with the approximation of 145 days arrived at by a similar process for

the growing season of 1920. It must be remembered, however, that this total was not available for the uninterrupted growth of the crop, as in other years, since the killing of shoots on March 29 and April 11–12 retarded the development of foliage and the production of bloom by approximately three weeks. There was a twofold effect upon the plants; their food reserves were reduced in direct proportion to the amount of growth at the time of the freeze, and there was also a reduction in the period of photosynthetic activity within which the development of foliage, the production of fruit, and the accumulation of stored reserves for next season's growth had to occur. This reduction of the effective photosynthetic period, considered alone, would be expected to produce a crop characterized by lower carbohydrate content than that of crops of other years. Other conditions were operating to mimimize this reduction, however, in that the maximum and mean temperatures were consistently higher than average throughout the growing season except in August, and the vines bore crops of fruit ranging from 30 to 80 per cent of the normal as result of the frosts. The fruit was adjudged in the field to be almost or quite up to the average dessert quality. Ripening was somewhat hastened, early and late maturing varieties ripening together. Picking was begun September 16 and completed on the 29th, several days earlier than usual. November was warm and rainy, the first killing frost occurring on the 6th, and severe cold and snow did not set in until the middle of December.

### Climatic Record for 1922

The deficiency of soil water resulting from the drought of 1921 was not made up in the early months of 1922, as the rainfall for the first five months totaled only 17.09 inches as compared with a normal of 18.81 inches for the period. The mean temperatures from January on through June were consistently 2.8° to 5° above normal, but periods of cool weather at the middle and end of March and until after the middle of April retarded plant growth and prevented the forcing of buds, and when a temperature of 30° occurred April 23 and 24 it did no damage in the vineyard (fig. 10). June and July were excessively wet, with 14.98 inches of rainfall, or one-third the total for the year. The rains of June were distributed mainly as showers over 15 days of the month. July had approximately the normal number of clear days in spite of more than twice the normal precipitation. August, like June, had a large number of cloudy, showery days and consequently less than normal sunshine, but the August rainfall was 0.5 inch below normal (fig. 11). The mean temperature was subnormal by

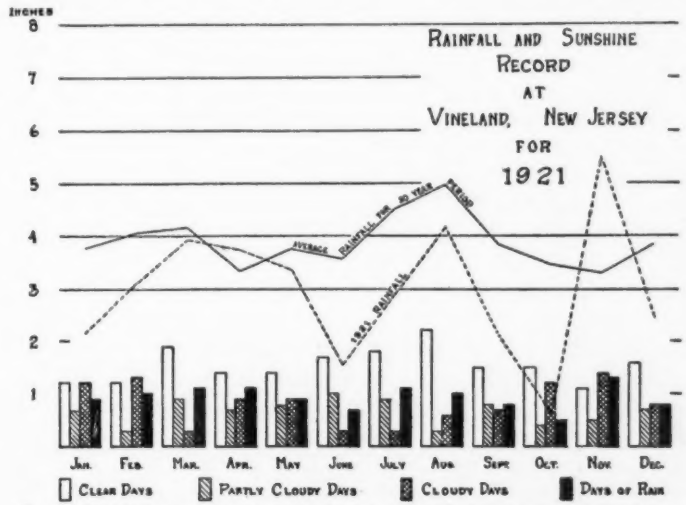


FIG. 9.—Rainfall and sunshine at Vineland, N. J., in 1921, with 50-year average for comparison

about 1° through July and August, rising again in September and remaining above average for the remainder of the year. September had more than the average amount of sunshine and only about two-thirds of the normal precipitation (which occurred on the 1st and 24th), and clear, hot weather continued through the middle of October. The crop matured perfectly and a little earlier than usual, picking having been begun September 14 and completed October 2. The crop was somewhat smaller in quantity than in other years, possibly about 85 per cent of normal, but was unusually uniform in that practically all varieties bore about the same amounts. The vines made exceptionally vigorous growth and the unusually heavy foliage was well retained until after the close of picking.

In point of sunshine received during the growing season—March to September, inclusive—the year was the least favorable of the entire period. It had 114 clear days, with 50 recorded as "partly cloudy." Applying the arbitrary method of valuation of partly cloudy days previously used, the whole period had the equivalent of 139 clear days, or 64.95 per cent, a smaller total than for any other year of the period. It is also worthy of note that that shortage of sunshine occurred in June and August, June having 11 clear and 10 partly cloudy days and August 12 clear and 10 partly cloudy days. The total of 139 days of sunshine probably permitted materially more photosynthetic activity than the 146 days of a like period in 1921 when the effect of frost in that year is considered, but it must also be remembered that the vines were bearing a considerably larger load of fruit in 1922 than they had in 1921, which would operate to reduce the carbohydrate content of the fruit.

The first killing frost of the autumn occurred October 21, about two weeks earlier than usual. October had a little more than one-third, November only one-fourth, the usual rainfall, and the mean temperatures were 3° to 4° higher than the average. December was very slightly above normal in rainfall and temperature with only 2.8 inches of snow.

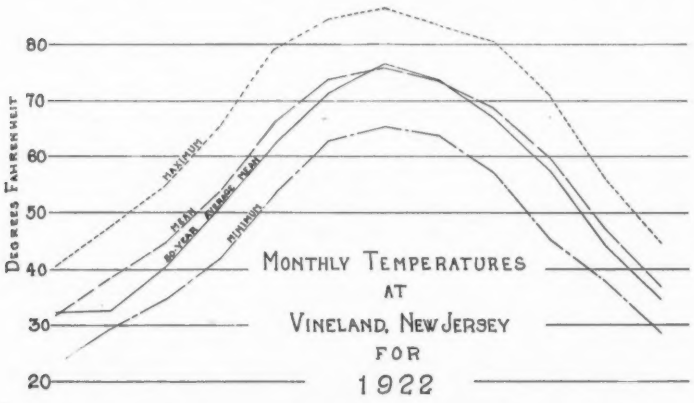


FIG. 10.—Maximum, minimum, and mean monthly temperatures at Vineland, N. J., in 1922, with 50-year average for comparison

## CLIMATIC RECORD FOR 1923

The winter of 1923 showed no unusual features aside from a prolonged cold period in the last half of February and a cold wave at the beginning of April. The resumption of growth was later than usual and was retarded considerably by cool weather in the first three weeks of May, which was very dry. June was the hottest month of the year, with high maximum temperatures, but the mean temperature was almost constant for June, July, and August, considerably exceeding the 50-year average in June, dropping a little below it in July, and rising in August to remain slightly above normal through November (fig. 12).

The distribution of precipitation during the first 11 months of 1923 departed widely from the 50-year average, as the precipitation was excessive in the winter months, then decidedly below normal in the period May to August, inclusive, then slightly above normal in September and October (fig. 13). The deficiency in precipitation up to December 1 was only 3.96 inches, but the fact that the four months May to August inclusive, received only 7.88 inches instead of the normal 16.58 made the period of development of the crop an unusually dry one. This condition was accentuated by the fact that much of the rainfall of May, June, and July was in the form of light showers of a few hundredths of an inch each, the only rains of 0.5 inch or more during the period being on June 29, July 3, and July 11. The precipitation of August was mainly in the form of three rains exceeding 0.6 inch each on the 5th, 20th, and 29th. The September rainfall, while exceeding the average in amount, occurred mainly in two rains of 1.58 and 2.20 inches on the 8th and 23d. October was rainless until after the completion of grape harvest on the 11th. Consequently the crop, which was the largest since 1918, ripened in a period of warm, bright, rainless weather and was considered at the time of picking to be the best crop of the period of observation.

The total number of clear days in the period March to September, inclusive, was 120, while 50 days were reported as partly cloudy. Employing the method of evaluating partly cloudy days previously used, the 214 days of the growing period had 150 days of sunshine, or 70.09 per cent. This is a larger percentage of sunshine than had been received by the crop during an equal period since 1919, but was somewhat below that of 1918 and 1919. It was unequally distributed over the period; the first four months had little cloudy weather and consequently received a total of 89 days of sunshine, or 22 per month; July, August, and September had unusually large percentages of partly cloudy days, only 12, 16, and 15 days, respectively, being reported as clear. While the total number of days of sunshine for the three months by our method of evaluation is 61, or 20 per month, the very considerable extent to which doubtfully valuable partly cloudy days enter into this total makes it certain that these months were less favorable for photosynthetic activity than the four months which preceded them. This was indicated by the late ripening

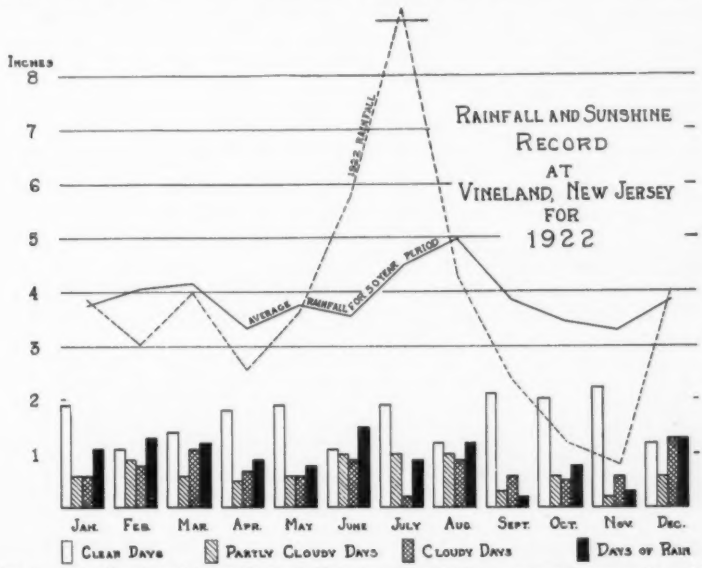


FIG. 11.—Rainfall and sunshine at Vineland, N. J., in 1922, with 50-year average for comparison. (All days on which a trace, 0.1 inch or less, was recorded are included)

of nearly all varieties, as picking was begun September 20 and extended through October 11, several days later than usual. In some degree the lateness of ripening added to the amount of sunshine received, as the whole period, September 20 to October 11, was one of clear warm weather, broken by rain only on September 23. The various varieties thus received 4 to 10 days of uninterrupted sunshine after the close of the period which has been considered for purposes of comparison. That there was very little if any actual shortage of sunshine as compared with 1918 or 1919 is indicated by the fact that the crop, which was the largest harvested during the five-year period, ripened normally, full characteristic color being developed in those varieties which do not color well in an unfavorable season. With practically no exceptions, the fruit of all varieties was regarded at picking time as of dessert quality fully equal to that of any previous year.

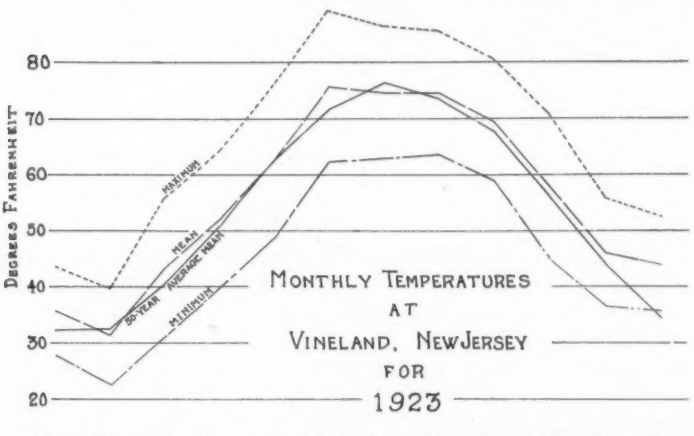


FIG 12.—Maximum, minimum, and mean monthly temperatures at Vineland, N. J., in 1923, with 50-year average for comparison

## CLIMATIC CONDITIONS AS RELATED TO VARIATIONS IN CHEMICAL COMPOSITION OF THE CROP

The seasonal conditions prevailing during the period covered by the studies of the crop have been described in some detail. The analytical results have been presented and the character and extent of the fluctuations in content of sugar, acid, and astringent constituents have been discussed. It remains to bring the climatological data and the analytical results together and to determine whether variations in the conditions under which the crop is produced exert discoverable and consistent effects upon the chemical composition of the fruit. If consistent mass effects appear under certain seasonal conditions, i. e., if a majority of a large number of varieties behave as one with respect to the chemical character of the crop, after individual variations have been eliminated by using composite samples made up of the entire crops of a considerable number of plants of each variety, one may feel warranted in the conclusion that seasonal factors are responsible for such mass effects.

The writer knows of no very extensive or exact studies upon this point to be found in the literature. Munson (*49*) publishes sugar and acid determinations, made with Oeschles' scale and Twitchell's acidometer, upon juices of 89 varieties grown at Denison, Tex., in 1906 and 1907. He remarks that the season of 1906 was excessively rainy and cool, and that the readings for sugar are all 5 to 20 points (Oeschle's scale) lower and the acid readings 1 to 4 points (Twichell's instrument) higher than in 1907, which was a much warmer and drier season (*49, pp. 123–125*), saying further that

> it is true that the degrees of sweet and acid vary with season, soil, condition and age of vines, and with change of weather, but varieties generally maintain their relative positions throughout the changes, with some unimportant exceptions.

Alwood (*2*, *3*) notes in connection with his studies of the development of sugar and acid in grapes during ripening, which were carried on in the Lake Erie district in 1908, 1909, and 1910, that the crop of 1908 was one of very exceptional quality, while that of 1909 was remarkably heavy, but that cold, rainy weather extended over the whole ripening period, some late varieties being partially defoliated and failing to ripen as a result. The crop of 1910 was reduced by May frost to about 40 to 60 per cent of normal. Alwood remarks that the sugar content of several varieties was 1 to 4 per cent lower, and the acidity was higher, in 1909 than in 1908, but does not present data as to the seasonal conditions prevailing during the other years of the study. The work of Kelhofer (*38*) and of Müller-Thurgau (*48*) on this point has already been mentioned (p. 1153).

The five crop years in which analytical data was secured have been roughly compared with one another in the discussion of the climatological data in a preceding section. Such a comparison involves a consideration of the varying factors—amount and distribution of rainfall and humidity, temperature, and sunlight—which enter into the makeup of a crop season, to the end that each may be evaluated with respect to its effect upon the plant, before any definite picture of the sum of all these effects can be obtained. Hedrick (*29*, *30*) has summarized climate, as it affects grape growing, in these six essentials: Length of season, seasonal sum of heat, amount of humidity in summer, dates of spring and autumn frosts, winter temperature, and air currents. While this basis holds good when distinct areas differing materially one from another in some of these factors are being compared, it does not apply to the present case. The climatic conditions at Vineland are such as to permit annual bearing of crops of normal size by a large number of varieties of early, medium, and late grapes. None of the elements of climate as enumerated by Hedrick is sufficiently variable to become a limiting factor upon fruitfulness. The analysis necessary here is upon a finer scale, since the variations encountered are such as merely to modify the crop in quality and chemical composition without markedly affecting the growth or vigor of the plants. As has been pointed out by Livingston and McLean (*44*), the growth of the plant automatically integrates all the fluctuating elements of the environmental complex, and the growth of a selected plant has been used as a means of measuring climatic conditions in different parts of an area, as in the work of McLean (*45*) and Hildebrandt (*31*). In the work of these writers the climatic

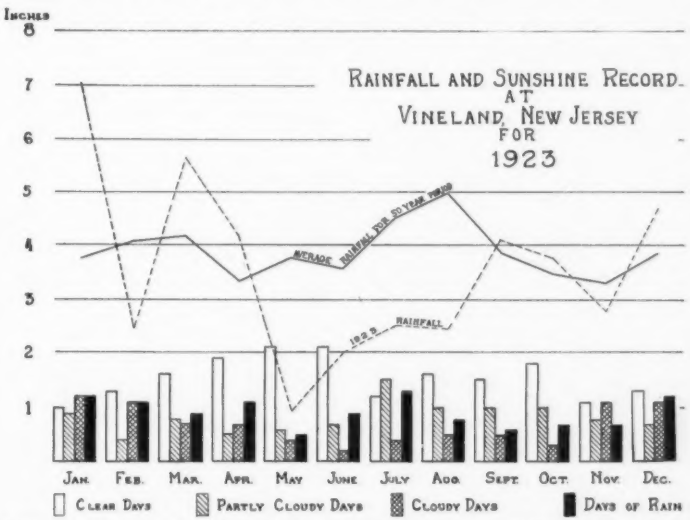


FIG 13.—Rainfall and sunshine at Vineland, N. J., in 1923, with 50-year average for comparison. (All days on which a trace, 0.1 inch or less, was recorded are included)

efficiency of various selected stations for growth of soy beans (variety Peking) was determined by growing the plants for four weeks from seed under controlled conditions and determining stem height, leaf area, and dry weight of tops. Hildebrandt has shown that there is no very close agreement between the instrumental measurements of the climatic data and the actual growth of the plants, the growth in some cases being greater, in others less, than expectation based upon climatic data. This study approaches the same general problem from a different angle, in that the plant employed is a long-lived perennial, and the climatic conditions are those of a single locality and did not vary widely enough to affect the annual growth or fruitfulness of the plants but only enough to alter the chemical composition of the fruit. It seems logical to assume that the automatic integration of the environmental complex by a perennial plant will be reflected in the chemical composition of the ripe fruit as truly as it is in the elongation and increase in dry weight of an annual.

If this assumption be true, it remains to be determined whether it is possible, by examination of the ordinary weather records of temperature, humidity, sunlight, and rainfall, to reach a dependable conclusion as to the nature of the effects which a particular set of seasonal conditions will have upon the composition of the crop. These factors are so intimately interrelated that even under the most complete control of experimental conditions thus far attained, it is difficult or impossible to modify the amount of sunlight received by a plant without modifying temperature and humidity. With plants growing in the open the mass effect of this interplay of factors is observed, but an attempt to analyze the result or determine the relative importance of the rôles played by the individual factors is usually considered unpromising. There is a possibility, however, that the interrelationship of these factors is of such a nature that they operate together to favor or depress photosynthetic activity in the plant. Thus excessive and long-continued rainfall is associated with decreased sunlight and lowered temperature, all of which operate together to depress the rate of photosynthesis, while drought implies maximum sunlight and high temperatures, which increase the rate so long as the plant has available an adequate water supply. Of course extreme modification of any factor may result in disturbance of metabolism and death, but within the limits of normal plant behavior seasonal changes consist in the modification of several or all the factors named in mass fashion, in a direction favorable or unfavorable to the plant. If this interlocking of climatic factors is sufficiently intimate and constant within the range of conditions in which normal growth is possible, it should be possible to find among the environmental factors some one which can readily be accurately measured and which will give a dependable indication of the direction in which all the factors have operated upon the plant during the season.

Under the conditions prevailing at Vineland the sunlight received during the growing period is such a factor. It is the factor which varies most widely from year to year. The nearness of the locality to the ocean renders it subject to fogs and periods of cloudiness and rain which extend over a very limited area and which cut off sunlight with much less accompanying depression of temperature than occurs during general rain over a wide area. Nearness to the ocean is also responsible for the absence of large differences in relative humidity and in temperature when the records of a number of seasons are compared. The equalizing effect of the ocean upon these factors throws the variable factors, rainfall and sunlight, into stronger relief than might be the case far inland.

Under these conditions there is a quite constant agreement between the sunlight received by the vines during the season and the composition of the crop. This of course does not mean that sunlight is the sole significant factor in determining the chemical composition of the crop but merely that in the locality of Vineland it is the dominant factor, other climatic factors playing subordinate parts and exerting their effects in the same direction. Whether there is such a correlation in regions remote from large bodies of water can be determined only by future work.

It is scarcely possible that the variations in amount and distribution of rainfall during the period exerted any direct effect upon the composition of the crop. The period as a whole was one of subnormal rainfall, the accumulated shortage for the years 1917 to 1923 inclusive being 15.76 inches, although one year (1919), had an excess of 12.61 inches. At no time during the period did the vines display evidences of distress from a shortage of water, although other crops suffered severely from drought in 1921, when there was a deficiency of 10.07 inches. As the vegetative

vigor and general condition of the vines in that year, with a total rainfall of 35.57 inches, compared favorably with that of 1919, with a total rainfall of 58.25 inches, as well as with that of other years of more nearly normal precipitation, the variations in rainfall can not have played a determining rôle in chemically modifying the crop.

Records of relative humidity were not kept at the Vineland station during the work. Detailed records are kept at Atlantic City and Philadelphia. Examination of these records indicates that the departures from normal humidity year after year are so inconsiderable as to make this factor of no significance, and the location of Vineland makes it very probable that the same conditions prevail there. The Vineland temperature records show very slight departures from the 50-year mean, which is no doubt due to nearness to the seacoast. These departures are too small to be significant when considered alone.

The climatic factor which stands out as varying most widely from year to year is the amount of sunlight received by the plants during the growing period. Location subjects the Vineland territory to occasional periods of overcast, cloudy weather at any time during the growing season and to frequent showers and fog in the late summer. The number of clear days in the period March 1–September 30, inclusive, varied as follows: 1919, 134; 1920, 110; 1921, 119; 1922, 114; 1923, 120. As pointed out in the discussion of climatic conditions, the number of clear days alone does not give an accurate idea as to the seasonal sunshine received, as partly cloudy days also contribute some sunshine. The number of days reported as partly cloudy are: 1919, 42; 1920, 70; 1921, 54; 1922, 50; 1923, 60. In the system of recording used by the Weather Bureau branch stations, days having four-tenths to seven-tenths of the hours of possible sunshine prevented by clouds are classed as partly cloudy. It has been assumed that in the aggregate the partly cloudy days furnish 50 per cent of the possible sunshine. It is probable that this approximates the actual facts as closely as is possible in the absence of an accurate detailed record.[12] The taking of 50 per cent as an average very probably somewhat underestimates the actual amount of sunshine received, but does not affect the results for purposes of comparison. Proceeding upon this assumption and adding to the clear days for each year one-half the number of partly cloudy days, we have for 1919, 155 days; for 1920, 145 days; for 1921, 146 days; for 1922, 139 days; and for 1923, 150 days. These figures present as close an approximation to the amount of sunlight in each of the years as can be arrived at from the data in hand. Ranked in the order of amount of sunlight, 1919 stands first, 1923 second, 1920 third, and 1922 fourth. 1921 must be separately considered, since the young shoots of most varieties were killed by frost, which retarded development for two or three weeks and reduced the size of the crop in that year. Consequently the amount of sunlight received during the season can not be used as a basis for comparing the crop with those of other years, as an unknown portion of the time, varying with variety, was required for recovery from the injury and the crop produced was subnormal in amount.

As has been pointed out in the discussion of the analytical data, 1923 had a slightly larger number of varieties attaining maximum sugar content than 1919, although 1919 had five days more sunlight in the period chosen for comparison. It was stated in the discussion of climatic conditions for 1923 that the year was one of late ripening, the harvest period extending through October 11, the fruit of the majority of the varieties remaining on the vines a week to 10 days longer than usual. As the period September 20 to October 11, inclusive, was one of high temperature and uninterrupted sunshine, conditions for photosynthetic activity were optimum, and the crop stored considerable sugar after the close of September. It is probable that by reason of this fact that this crop received fully as much sunlight as did that of 1919. The two years are characterized by the large number of varieties having high sugar, 1919 having 15 with maximum and 12 with next-to-maximum quantities, while 1923 had 18 with maximum and 17 with next-to-maximum contents. That years of high sunshine are also years of generally low acidity is also clear, 1919 having the maximum in 20 varieties and next-to-maximum in 9. Astringency determinations were made only for the years 1921–1923, inclusive,

[12] It is probable that there is considerable variation in the use of the term "partly cloudy" by different observers. For example, the record for March, 1921, at Atlantic City, states that the 8th, 12th, 21st, 22d and 27th had 92, 97, 89, 91, and 98 per cent of possible sunshine, yet it classes them as partly cloudy, while March 14, 1923, is classed as clear, although it is recorded as having 69 per cent of possible sunshine. July 9, 1923, is recorded as partly cloudy, yet as having 100 per cent possible sunshine. (Monthly Meteorological Summary, Atlantic City, N. J., Form 1030, for dates given.)

but the year 1923 was remarkable for the fact that 42 varieties out of 49 showed minimum total astringency for the three-year period in that year. This was due to the fact that both true tannins and astringent nontannins were low, 20 varieties having minimum tannin while 44 had minimum nontannin in 1923. From the results one might conclude that in this year high sugar content was associated with low acidity and low total astringency, and that the latter was due to a low content both of true tannin and astringent nontannins.

The year 1920 had a total of 145 days sunlight as the effective period for photosynthetic activity. In sugar content the crop ran low, only 4 varieties showing the maximum, while 13 had minimum and 14 next-to-minimum figures. In acid content there were 13 with maximum and 8 with next-to-maximum content. The general tendency is to run medium to low in sugar and high to medium in acid, minimum acid and maximum sugar being equally rare. No astringency determinations were made on the fresh juice.

The year 1922 was the least favorable for photosynthetic activity of the four comparable years, having only 139 days of sunshine in the crop period. The sugar content in the crop as a whole was lower than in 1923, 17 varieties having minimum and 10 next-to-minimum content, while only two had maxima. Associated with low sugar was an outstanding high acidity, 19 varieties having maximum and 17 next-to-maximum acid content. With high acid readings there was associated distinctly high astringency, 35 having the maximum for the three-year period. Thirty-three had maximum true tannins, while 27 had maximum astringent nontannins. Here low sugar content, high acidity, and high total astringency resulting from high tannin and high astringent nontannins are found associated. This fact, coupled with the fact that the fruit ripened somewhat earlier than usual, led to delay in picking some varieties until they were slightly overripe. The flavor of the fruit was so affected by the altered composition that it was difficult to convince one's self that it was fully ripe even when it showed all the physical signs of ripeness.

This review of the data for the four years of normal crop conditions indicates that there is a considerable degree of correlation between the fluctuations in certain chemical constituents of the grape. High sugar content is associated with low or less-than-medium acidity and total astringency; low sugar content is associated with high acidity and high total astringency. While there are individual exceptions, there is a clearly marked mass tendency, the majority of varieties behaving as one throughout the period. It is clear that this mass behavior is a response to the seasonal conditions of the years concerned. The year 1921 has thus far been excluded from consideration by reason of the abnormal conditions of that year, namely, a spring freeze with resulting shortening of the growing period and reduction of the crop, which precludes consideration of the data on the same basis as those of other years. In view of the correlation between sugar, acid, and astringency found to exist in the other years, it becomes a matter of considerable interest to know whether this correlation continues to hold or breaks down in an "off-year" of abnormal conditions and reduced crop. The data for 1921 will therefore be reviewed somewhat in detail for the light it may throw upon this point.

The graphic summary on sugar and acid content, Figure 1, can not be employed for this purpose, for the reason that it summarizes results which must be segregated in order to be properly interpreted.

As stated in the discussion of seasonal conditions for 1921 (p. 1164), 13 varieties suffered no injury from the frost. Ten of these, namely, Agawam, Cynthiana, Franklin, Herbemont, Lenoir, Missouri Riesling, Noah, Norton, Vergennes, and Wilder, bore crops of full normal size. The analytical data for these is entirely comparable with that for the other years, and may be considered on the basis of the sunlight received, which exceeded by one day that of 1920. Reviewing the data for these 10 varieties separately, 1 has maximum and 1 next-to-maximum sugar, 4 stand in third place, 3 in fourth place, and 1 has the minimum. In acid 1 has maximum, 1 next-to-maximum, 3 in third and 3 in fourth place, while 2 are minimum. The majority of the varieties are consequently midway between extremes, thus recalling the situation found in 1920. In astringent constituents, 4 have maximum total astringency, 1 has the minimum, and 5 are intermediate. In true tannins 2 have the maximum, 8 the minimum, while 6 have maximum nontannins, and 4 next-to-maximum. The general situation with these 10 varieties is therefore one of medium sugar and medium acid content with

medium to high total astringency, high astringency being due in the majority of cases to a high content of astringent nontannins.

The remaining varieties suffered more or less severely from the freeze, they losing two to three weeks of the effective period for photosynthetic activity and their crops were reduced to 30 to 85 per cent of the normal. It is of interest to ascertain to what extent the crop produced under the abnormal conditions tends to show the same correlations in composition as are found in other years. Summarizing the data, we find that 9 varieties had maximum, 7 next-to-maximum sugar content, 4 stood in third place, 9 in fourth place, and 10 had the minimum. In acid content there were no maximum, 7 next-to-maximum, 17 in third place, 10 next-to-minimum, and 5 minimum. In total astringency 9 had the maximum, 3 the minimum, and 25 were intermediate. As regards true tannins, 6 had the maximum, 16 the minimum, and 15 were intermediate, while 15 had maximum nontannins and 21 an intermediate amount, there being none with the minimum. The majority of these varieties occupy an intermediate position in their sugar, acid, and total astringency, but there are some maximum and minimum results upon sugar. An examination of these in detail will constitute a rather crucial test of the persistence of the correlation found elsewhere, since the varieties having maximum sugar were those having greatest reduction in the crop (40 per cent or less) while those showing minimum sugar had 60 to 85 per cent of a normal crop. (See Table III.) Expressed in another way, plants having comparable amounts of foliage were storing sugar in crops of very unequal size; the plant with a very small crop brought its fruit to a high sugar content in the same time and under the same conditions that permitted the plant with a crop of approximately normal size to store only a minimum.

Of the 9 varieties attaining maximum sugar content in 1921, 3 had minimum acid, 2 next-to-mimimum, and 4 stood in third place, there being no maximum or next-to-maximum cases. Two had maximum and 7 next-to-maximum astringency. For the varieties having minimum sugar content, 5 had next-to-maximum acidity, 3 stood in the third place, and 1 in fourth, while 6 had maximum and 3 next-to-maximum total astringency. Thus, nearly all the cases of extremes in sugar, acid, and total astringency are related, high sugar being accompanied by low acid and astringency and low sugar by the opposite condition. The remainder of the crop was made up of individuals characterized by the absence of extremes in any particular, sugar, acid, and astringent constituents alike being intermediate in amount between the high and low figures occurring in other years.

Summarizing, two outstanding conclusions are to be deduced from the results of this study. First, the amount of sunshine received during the period March 1 to September 30, inclusive, is, for the five years of this study, a dependable index of the sugar content of the crop of grapes produced by a large number of varieties each of which was bearing annual crops of average or normal size. Under the conditions of the experiment, the amount of sunshine received during the growing season is the only climatic factor which varied widely from year to year, hence it determined the amount of photosynthetic product accumulated in the crop. While there are individual exceptions, the majority of varieties behave quite uniformly as one throughout the experimental period.

Second, there is a consistent and fairly high degree of correlation between sugar, acid, and total astringent content, extending through the experimental period. The nature of this relationship is such that a high content of sugar is found associated with low or medium content of acid and of astringent constituents, a low content of sugar is associated with high acidity and astringency, while an absence of extremely high or low sugar content is accompanied by an absence of extremes in acid and astringency. While there are some exceptions, this general statement holds not only for four years of normal crops but also for a year in which frost injury materially reduced the crop. In every year there is an evident mass tendency to behave in the manner stated.

The explanation of this situation would appear to be that the content of each of these constituents present in the grape at maturity is conditioned by the amount of sunlight received by the plant during the formation of the crop. Conditions which favor a maximum accumulation of the products of photosynthesis in the fruit also favor the reduction of the content of acid and astringent constituents to a low or minimum point. Conditions which minimize photosynthetic activity depress the accumulation of sugar in the fruit to a minimum and at the same time depress the reduction of

acidity and astringency, leaving these constituents at a high level. Intermediate conditions result in the production of a crop characterized by the general absence of extremes in the amount of any of these constituents. There are occasional exceptions to each of these statements to be found in the data, but there is a clear general tendency to behave in the manner indicated.

There is no immediate or rigid relationship between acid content and total astringency as regards their behavior under a given condition; both react in the same direction but in varying degree. The same statement holds for the gelatin-precipitable and nontannin constituents grouped together as total astringent substances. The amounts of tannin and nontannins present fluctuate rather widely from year to year, and these fluctuations are to a considerable degree independent, and in consequence there are a number of cases in which total astringency content does not fulfill expectation for the reason that the two constituents did not behave in the same way. A general tendency is clear, however, and it is possible that the accumulation of more data, together with the extension of our knowledge as to the real nature of the substances at present grouped under the designation astringent nontannins, would furnish an explanation of the inconsistencies in behavior here reported.

It would seem in the light of the results given here that the climatic conditions during the growing period of the grape crop, or more specifically the amount of sunshine received, when other conditions are constant, bear such a relation to the chemical character of the crop that the general chemical character of the crop may be predicted from a knowledge of the effective period of photosynthetic activity.

## SUMMARY

Chemical analyses of the juices of a collection of 66 varieties of grapes grown together under controlled conditions at Vineland, N. J., were made annually during the five-year period 1919 to 1923, inclusive. The determinations made included total solids, free reducing sugars, total sugars after inversion, titratable acidity, total astringency, and nontannin astringency.

The range of variation in composition of the juice of any variety grown under constant conditions in one locality through a series of years is much narrower than the variation encountered when a large number of samples of a given variety grown over a wide area and under a variety of cultural conditions are compared. Differences of soil and cultural conditions appear to affect varietal composition more profoundly than do variations in environmental conditions encountered over a series of years in one location.

Cane sugar is of widespread but very irregular occurrence in the varieties of grapes here studied, having been found at least as a trace in all but one variety. Its presence is in some degree indicative of immaturity of the fruit, but it is often found in fully mature or overripe grapes. Its presence can not be definitely correlated with any other factor such as temperature, insolation, water supply, or load of fruit borne by the vine.

There is a very definite and clearly marked effect of climatic conditions during the growing season upon the total sugar content, total astringency, and titratable acidity of the fruit produced during that year. This effect is a mass effect, all the varieties responding to a given set of climatic conditions in the same manner.

Of the various climatic factors entering into the composition of the seasonal conditions at Vineland, the amount of sunshine received during the period March to September, inclusive, is subject to the greatest annual variations and is the dominant factor in determining the chemical character of the crop.

Under the conditions prevailing at Vineland, the content of sugar, acid, and astringent substances present in the juices of fully ripened grapes from normally loaded vines seems to be determined very largely if not altogether by the number of days of sunshine occurring in the period of 214 days between March 1 and September 30.

In vines bearing annual crops of comparable size, the year of maximum sunshine during the period March to September, inclusive, was the year of maximum or next-to-maximum sugar content of juice in a majority of all varieties. The year of minimum sunshine for the period March to September, inclusive, was the year of minimum or next-to-minimum sugar content for a majority of all varieties in which the vines bore normal crops. Years having amounts of sunshine intermediate between these extremes during the growing period have amounts of sugar intermediate between the extremes and proportional to the amount of sunshine received.

The year of maximum sunshine during the growing period was the year of minimum acid content and minimum total astringency content in a majority of varieties, while the year of minimum sunshine during the growing season was the year of maximum titratable acidity and total astringent content in a very large number of varieties. Years intermediate between the extremes in amount of sunshine received are intermediate in the amounts of acid and astringent materials present, and these amounts are inversely proportional to the amount of sunshine for the growing season.

Conditions which permit a maximum accumulation of sugar in the fruit also favor the reduction of the titratable acidity and astringent content to a low or minimum value. Conditions which minimize photosynthetic activity and accumulation of sugar depress the reduction of titratable acidity and astringent content of the fruit.

Titratable acidity and total astringency of a fruit juice are affected in the same direction, but independently and in varying degree, by the conditions prevailing during the maturing and ripening of the fruit.

Under the environmental conditions in which this work was carried out, the amount of sunshine received during the period of growth is the dominant factor in determining the chemical character of the fruit of a large number of grape varieties of widely differing parentage and character of fruit. A knowledge of this factor, when the climatic factors vary within a relatively narrow range as at Vineland, may enable one to forecast the general chemical character of the crop to be produced.

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# NATURAL REPRODUCTION AFTER FOREST FIRES IN NORTHERN IDAHO[1]

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## INTRODUCTION

This study of natural reproduction following some of the largest and most destructive forest fires in northern Idaho was made, in 1923, with the object of discovering in what way and to what relative extent the several species of conifers reseed the ground, and to learn what factors, such as intensity of the fire, differences in site or stand conditions, or seed production of the forest, affect natural restocking.

In the fall of 1923 studies were made on large burns on the Coeur d'Alene National Forest—on areas burned only once, which was in 1910, and on areas burned twice at different intervals by fires which occurred in 1870, 1889, 1910, and 1919.

## FIRE HISTORY

### BURN OF 1870

The earliest large burn studied occurred about 1870. This burn killed approximately 3,200 acres of mature timber on Trail Creek and its tributary, Bear Creek, a mile or so to the west of Magee Ranger Station. (See fig. 1.) The numerous groups of seed trees which still exist on the higher points, as well as the comparatively small area burned, strongly indicate that conditions were not so arid nor the fire so intense and destructive as in the burns of 1910 and 1919. The Trail Creek area reseeded quite generally after the 1870 burn, but the stand that followed was almost completely killed in 1910. Here opportunity was afforded for a study of reproduction after fire had destroyed a young 40-year stand.

### BURNS OF 1889 AND 1910

A later burn of greater consequence, that of 1889 on the Deep Creek area, covered the upper south and west slopes along the Idaho-Montana divide. This was part of a very general fire which originated near Pend Oreille Lake and swept large areas in the Clark Fork Valley to the north. These areas reproduced well but burned again in 1910, leaving very little inflammable material, so little in fact as to prevent the 1919 fire from crossing over into Montana. The coincidence here of the 1889 and 1919 burns permitted the study of natural reproduction following the destruction of a 30-year stand.

The large and very destructive fire of 1910 occurred about August 20. It began in the Magee district and swept in a path 7 to 9 miles wide and 18 miles long to the Idaho-Montana divide. The destruction was quite general and complete. Only here and there on bottoms, lower north slopes, high points, or on very rocky sites did groups of trees survive. The most clear-cut cases of single 1910 burns were studied on Alder Creek.

### BURN OF 1919

The large fire of 1919 made a fairly complete clean-up of the dead material left by the 1910 burn, covering high and low points alike. It stopped when it reached the upper south slopes of the Idaho-Montana divide, laid bare by the two earlier fires of 1889 and 1910. Opportunity was afforded here for a study of natural reproduction following a very large and intense double burn, on a thousand acres of which there remained not one live tree. In two other sections with large open north and south aspects only a few isolated groups of green trees survived both fires.

## CHARACTERISTICS OF BURNED AREAS

The study as a whole gave evidence of certain outstanding typical conditions which appear and reappear on different parts of large burned areas and which are due to similarity of slope, aspect, and elevation. That is, where the topography is similar the results from burns are similar, provided

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the stand or forest is uniform. This principle, of necessity, is of first importance in the application of the data obtained by this study. On this basis, the results of single or repeated burns are treated separately according to the following topographic subdivisions:

1. Lower north and east aspects.
2. Middle north and east aspects.
3. Upper north and east aspects.
4. Lower south and west aspects.
5. Middle south and west aspects.
6. Upper south and west aspects.
7. Bottoms.
8. Draws.
9. Benches.
10. Tops.

Further subdivisions of each of the above locations may be made according to minor local variations of each.

### DEEP CREEK AREA: BURNS OF 1910, 1919, AND 1889

The Deep Creek area was selected because the large and severe fires of 1910 and 1919 ran rampant there in virgin western white pine timber, and because there had been neither grazing nor lumbering either before or after the fires (pl. 1, B).

Descriptions and records of the forest composition previous to 1910 do not exist. It is evident from what now remains that the entire watershed contained magnificent stands from 200 to 300 years old of western white pine (*Pinus monticola*), western larch (*Larix occidentalis*), Douglas fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanni*), lowland fir (*Abies grandis*), and alpine fir (*A. lasiocarpa*). The white pine occurred on all aspects up to 4,500 feet, giving way to pure Douglas fir only on the high south slopes. Engelmann spruce was confined to the stream bottoms and lower north slopes. Western hemlock stands were heavy on north aspects. Larch showed up strong on north slopes and terraces, while lodgepole pine occurred mostly on the sharper knolls or hog backs with south and west exposure.

After looking over the Deep Creek burn, it was decided to concentrate on a rectangular area roughly designated in Figure 1. A great advantage found in this selection was the possibility of detailed study of different aspects by means of a system of strips radiating from a central point.

Detailed records of field conditions and natural reproduction were obtained on chained compass strips. Counts of reproduction by species were made separately for each chain on a strip either 10 or 20 links in width. Seedlings the ages of which could not be definitely determined were merely tallied. Record was made of live and dead trees by species. All live trees near the strip or within plain view were also noted. It was impossible, without detailed study, to be sure in all cases of the species of dead trees, especially on the double burn. The records included species of vegetation present, the density of the vegetative cover from the standpoint of shading or competition, soil conditions, aspect, and degree of slope.

### TRAIL CREEK AREA: BURNS OF 1910 AND 1870

This part of the 1910 burn is a wedge-shaped area of about 200 acres, lying south of Trail Creek and rising with regular slopes and uniform grades from 3,100 to 4,000 feet elevation, with northwest and northeast aspects (fig. 2). The timber here was more than 200 years old, very dense and tall, with a high percentage of white pine; the soil was moist, deep, and fertile. This permitted a study of natural reproduction on a clean and complete 1910 burn where no green trees survived the fire.

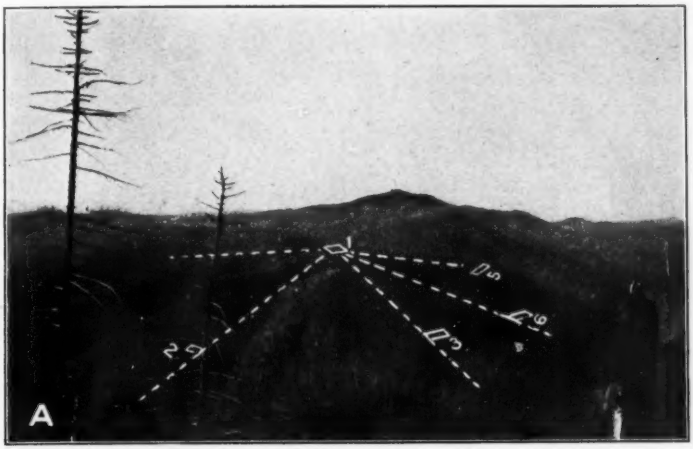
Another tract studied lies on a broad spur terminating at the junction of Trail Creek and Bear Creek (fig. 3). The somewhat uniform slopes, which rise from 3,100 feet to 3,600, are interrupted by several deeply cut draws. This affords local variations in aspect which show striking differences in flora and natural reproduction. Here it was that the mature forest—including western white pine, western larch, and Douglas fir—was largely destroyed about 1870 and where the dense and vigorous young forest attained a 40-year growth and was completely burned in 1910.

### DOUBLE BURN: 1910 AND 1919

#### VARIOUS ASPECTS

The first point of attack was the double 1910 and 1919 burn on Deep Creek. Here the elbow of the river has formed a round peninsula which tapers up to a central point at 4,100 feet elevation, as shown in the smaller western section of the inclosed area in Figure 1. This offered an excellent opportunity for studying reproduction on different aspects.

Both the big fires of 1910 and 1919 struck this point very hard, making a fairly clean sweep of all live trees in




A. Looking west across Deep Creek, where two very severe fires (1910 and 1919) destroyed all living trees except some tall larches on the lower north aspect. Dotted lines show location of plots and courses of count strips

B. View north along Deep Creek from point between Deep Creek and Jordan Creek. Horizontal Prichard slate and steep lower slopes capped by the gentler intermediate slopes of the overlying Burke formation. The middle of the skyline is formed by the Idaho–Montana divide, toward which both the 1910 and the 1919 fires traveled

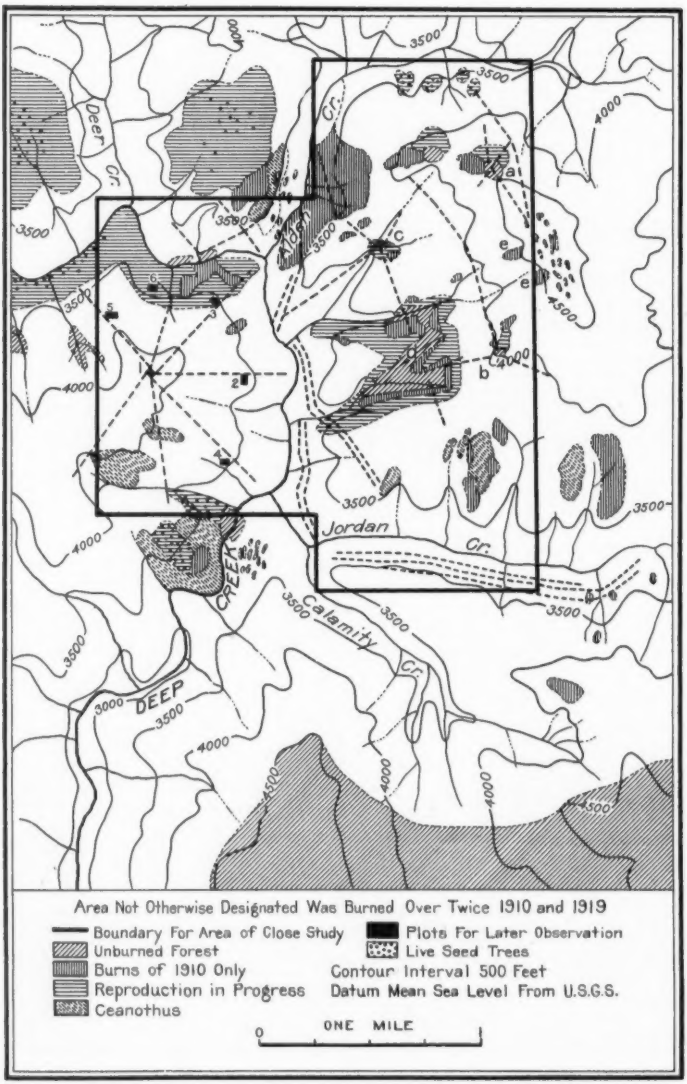



FIG. 1.—Double burn of 1910 and 1919 on Deep Creek area, Coeur d'Alene National Forest, Idaho

the first burn, and on the south and east aspects killing all trees except an occasional larch. On the north slopes, particularly the lower parts, several large western larch survived the 1910 burn but were killed in 1919. The north aspect also showed patches of reproduction which followed the 1910 fire and which escaped the 1919 fire.

Beginning at 4,100 feet elevation, seven radiating strips were run down to the river, some of them shown in

1. Insufficient natural reproduction on all aspects.
2. Deplorably small numbers of white pine everywhere.
3. Restocking up to 200 seedlings per acre of western larch on north aspect.

The western larch reproduction consisted of 2, 3, and 4 year old seedlings, the largest percentage by far being 4-year-olds which followed the 1919 burn. Seedlings of white pine occurring on the double burn were found to be 1, 2, and 4 years old. There was no

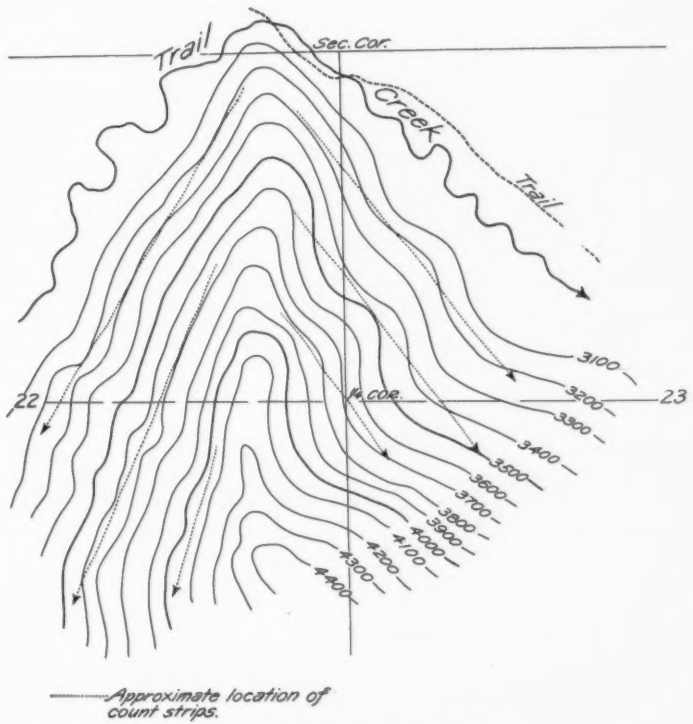



FIG. 2.—Map of portion of 1910 burn, Trail Creek

Plate 1, A. Reproduction was counted on these strips. In addition, six plots—one of one-tenth acre, the rest one-quarter acre—were established on the different strips at intermediate elevations. Four of these are shown in the illustration; all can be seen in Figure 1. The seedlings on the plots were counted and staked, with the results given in Table I. The reproduction on these plots will be examined in later years. The main deductions from Table I are:

evident relation between the original stand and the reproduction, except in the case of western larch.

The fact that 1-year-old seedlings of white pine, and occasional seedlings of Douglas fir, and even white fir, from 1 to 4 years old, were found, indicates strongly that a very sparse long-range seeding is in progress. If white pine only had been found it might have been assumed, as one possible explanation, that the seed had been scattered in 1919 at the time of the fire, and that

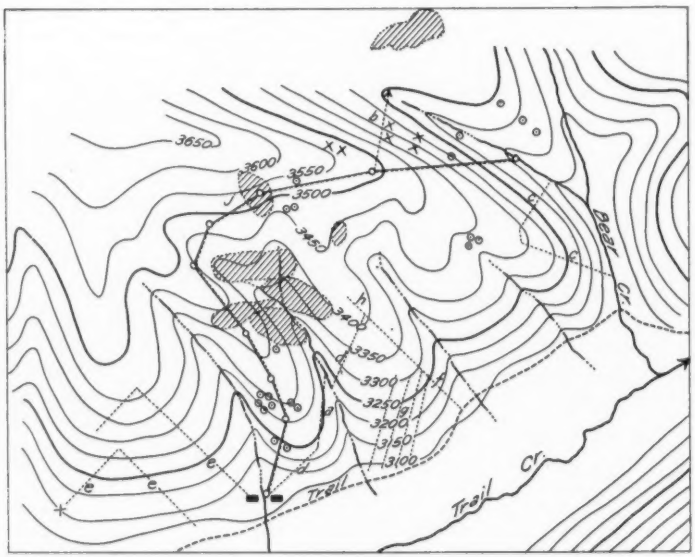
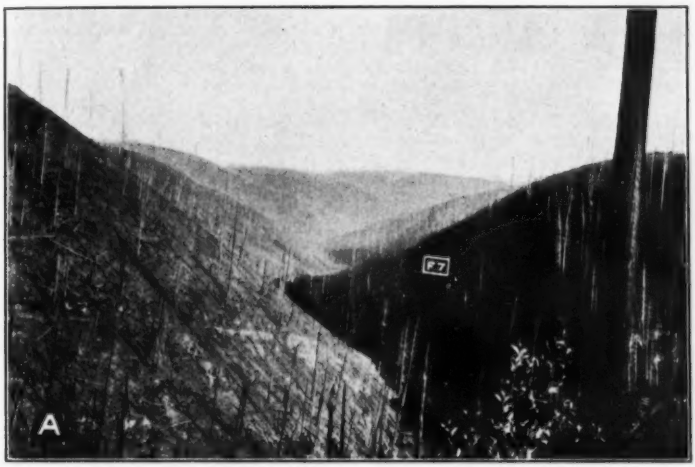


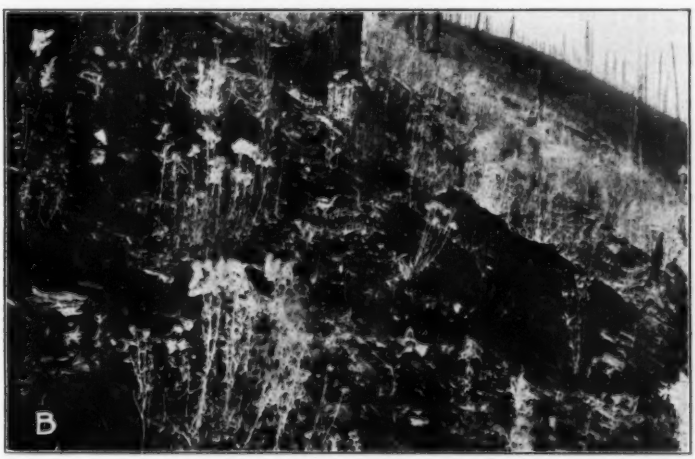

FIG. 3.—Map of portion of Coeur D'Alene National Forest

TABLE I.—*Double burn of 1910 and 1919: Reproduction count on permanent plots, all aspects; compared with average for strips*

| Species | Seedlings per acre by plots | | | | | | | | Seedlings by count strips | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. 1 top | No. 5 NW. | No. 6 N. | No. 3 NE. | No. 2 E. | No. 4 SW. | Average per acre | Percentage by species | Average per acre | Percentage by species |
| Western white pine | 50 | 0 | 8 | 8 | 0 | 0 | 6.7 | 10 | 2.2 | 5 |
| White fir | 0 | 0 | 16 | 0 | 0 | 0 | 3.0 | 4 | 1.4 | 3 |
| Western larch | 20 | 12 | 168 | 104 | 8 | 16 | 58.5 | 83 | 36.4 | 84 |
| Douglas fir | 0 | 4 | 0 | 0 | 4 | 0 | 1.5 | 2 | 0 | 0 |
| Western hemlock | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.3 | 3 |
| Lodgepole pine | 10 | 0 | 0 | 0 | 0 | 0 | .7 | 1 | 1.3 | 3 |
| Engelmann spruce | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 2 |
| Alpine fir | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 80 | 16 | 192 | 112 | 12 | 16 | 70.4 | 100 | 43.3 | 100 |
| Area of plots (acres) | 0.10 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | | | | |
| Percentage of slope | 10 | 25 | 60 | 60 | 45 | 45 | | | | |




A. View east up Jordan Creek. Through the narrow canyon in the foreground both the 1910 and 1919 fires rushed to reach the upper basin. Natural reproduction is utterly inadequate




B. Near view on middle north slope, Deep Creek, showing complete destruction by the two hard burns of 1910 and 1919. Vegetation is mostly pearly everlasting. Reproduction plot No. 6 was located here

some of this seed had "delayed germination," but other species whose seed does not hold over are also present as 1-year-olds. This seems to be strong evidence of seed dispersion for distances of a mile or more.

South of Alder Creek is a long and steep north slope from 3,000 to 4,700 feet in elevation. This was heavily burned in 1910 and 1919, and all green timber was destroyed except a few larches on the lower part of the slope. Here the natural restocking is extremely irregular and entirely insufficient. Strangely enough, on this north slope no new white pine seedlings were found. The nearest white pine trees which could have furnished seed are part of a seed group remaining on top of a knoll less than one-half mile to windward. Occasional new Douglas fir and lodgepole pine seedlings were found, and these might well have come from this same seed-tree group. Seedlings of western larch 3 and 4 years old formed 88 per cent of the total, and unmistakably showed their relation to large parent trees surviving the 1910 burn and killed or dying as a result of the 1919 fire.

One of the most completely devastated slopes met with in this study is the north aspect toward Jordan Creek (pl. 2, B). Here was formerly a dense and mature forest containing much splendid white pine and some western larch, white fir, and hemlock. Both the 1910 and the 1919 fires raced up the narrow Jordan Creek canyon shown in the foreground of Plate 2, A, making an unusually clean burn. Even the stumps and roots of the trees were burned, in many places leaving nothing but holes to indicate where the trees had been. The rocks showed marked coloring as a result of the heat, and the soil is now apparently very poor and has deteriorated, as evidenced by unusual coloring, a large amount of rock material near the surface, and the short and scant vegetation. On a strip a mile long, covering an area of 4 acres, not more than 12 new seedlings were found. These were 3 white pines 2 years old, 2 white firs, 2 Douglas firs under 4 years, and 5 western larches 4 years old. On the north aspect, where the second fire had been less intense, were eight small patches of seedlings which had come up after the 1910 burn and which had escaped the 1919 fire. Here, as well as on the previous double-burned north slopes, natural reproduction is decidedly insufficient.

### UPPER SOUTH AND WEST ASPECTS

The land directly to the east of Deep Creek slopes to the southwest from 4,700 feet at the top to 3,000 feet elevation at the river. The rise for the first 500 feet from the river is quite steep, then follows an intermediate benchlike slope interrupted by deep draws. Above 4,000 feet the land is again very steep. The slopes are uniform on the whole, and regular and free from débris. The soil is generally deep and fertile, but there are many barren and shallow stretches at the apexes of the several spurs and on the lower and steeper portions near the river. Both the 1910 and 1919 fires played great havoc with the lower and upper slopes but spared several bodies of green trees in the principal draws (fig. 1).

One count strip was run horizontally along the entire length of the upper southwest aspect, and another lower down, as shown on Plate 3, A. The counts are given in Tables II and III.

Table III shows a total of only 14 seedlings per acre on the upper south slope and 50 on the lower. As indicated in Table II, these seedlings are 1 to 4 years old. Only 14 per cent on the upper slopes are western white pine. This site is directly exposed to the sun and wind, so that seedlings, especially of the white pine and western larch, would be likely to dry out in great numbers, except those in the shade of logs or stumps. In fact, most of those found were where the slope swings to the northwest.

TABLE II.—*Reproduction count by age classes on parallel strips, double burns of 1910 and 1919, upper and middle southwest aspects*

| Age class | Upper strip, seedlings per acre | | Lower strip, seedlings per acre | |
|---|---|---|---|---|
| | *Number* | *Per cent* | *Number* | *Per cent* |
| 1 year old | 0 | 0 | 4 | 8 |
| 2 years old | 4 | 29 | 4 | 8 |
| 3 years old | 6 | 42 | 4 | 8 |
| 4 years old | 4 | 29 | 38 | 76 |
| Total | 14 | 100 | 50 | 100 |

TABLE III.—*Reproduction count by species on parallel strips, double burns of 1910 and 1919, upper and middle southwest aspects*

| Species | Upper strip | | | Lower strip | | |
|---|---|---|---|---|---|---|
| | Dead trees | Seedlings per acre | | Dead trees | Seedlings per acre | |
| | *Per cent* | *Number* | *Per cent* | *Per cent* | *Number* | *Per cent* |
| Western white pine | 25 | 2 | 14 | 44 | 19 | 38 |
| White fir | 5 | 7 | 50 | 6 | 0 | 0 |
| Western larch | 16 | 3 | 22 | 21 | 31 | 62 |
| Douglas fir | 42 | 2 | 14 | 0 | 0 | 0 |
| Western hemlock | 12 | 0 | 0 | 26 | 0 | 0 |
| Engelmann spruce | 0 | 0 | 0 | 3 | 0 | 0 |
| Total | 100 | 14 | 100 | 100 | 50 | 100 |

LOWER SOUTH AND WEST ASPECTS

The lower south and west slopes are, as stated, much steeper than the middle or upper. The soil is thin, vegetation sparse, and rock material much in evidence. (Pl. 3, B.) Both fires burned very hard, leaving no green trees. Close examination was made of the southerly aspects on Deep Creek and some distance up Jordan Creek, but except for an occasional western larch seedling growing in a shaded place no reproduction could be found. Some seeds very likely fell on these slopes after the 1919 burn, but if any did they probably met with such adverse conditions of heat and drought that any seedlings that came up died during the first and second seasons after germination, which would be expected in the light of the results of studies made at the Northern Rocky Mountain Forest Experiment Station.

BOTTOMS

Reproduction on the bottoms, river flats, or flood plains along the main creeks has not been investigated to any great extent. Conditions differ greatly on such sites, making classification very difficult, for there are variations all the way from moist, deep, loamy soil, covered with a wealth of grasses, to thin, shallow soil or pure gravel. The original stand of trees also varies greatly. On the Deep Creek bottoms there has been considerable spruce, white fir, and white pine. It may safely be said, however, that good reproduction on these sites has followed the single 1910 fire and not the second fire, except in the vicinity of seed trees.

BENCHES

The benches or high terraces are those lying between the 3,500 and 4,000 foot contours. Here the first burn of 1910 killed all species except western larch, the larch being left irregularly distributed over the area. The larches seeded and restocked abundantly after the first fire, as witnessed by small patches of reproduction which escaped the later 1919 burn. Many of the thick-barked larch seed trees survived both fires and are now furnishing seed for restocking.

TOPS AND KNOLLS

One very pronounced characteristic, which has appeared repeatedly on both the Deep Creek and the Trail Creek areas, is the greater numbers of lodgepole pine seedlings occurring in fairly solid bodies on dry southerly points and on thin soil between the lower steep south or west slopes and the terraces. Seed-bearing lodgepole pine was present on these sites in goodly number before the 1910 burn and seeded in well afterwards, and wherever this reproduction has survived the 1919 conflagration it presents a solid mat of lodgepole saplings about 10 to 13 years old, usually with a smaller number of shorter white pine seedlings included. The knolls and ridge tops which burned hard in both 1910 and 1919 show no reproduction, but many such spots escaped one fire, and in some cases both fires.

INFLUENCE OF SEED GROUPS

It is now necessary to examine the records of seed dispersion from groups of trees which by reason of the influence of topography in checking or abating the fury of a fire at certain points survived both the 1910 and 1919 fires. Such groups usually occur on high, sharp ridges, on very rocky ground, in deep sharp draws, or on moist bottoms. A study was made of

A. View east across Deep Creek to the double burn of 1910 and 1919 on southwest aspect. Seed group of western larch is to be seen on a ridge to right of center; remnants of the 1910 burn on left and double-burn south aspect below. Horizontal dotted lines mark count strips

B. Near view of steep lower south aspect, Jordan Creek, showing effect of soil leaching and dense grass vegetation; natural reproduction nil. Though seed would fall here by long-range dispersion, the seedlings would be at a serious disadvantage

dispersion of seed from four such seed groups, which appear as *a*, *b*, *c*, and *d* on the map, Figure 1, and also in Table IV.

Group A is a high and very prominent group and is shown on the elevation in the background of Plate 3, A. The greatest number of trees in the group are western larch, but there are also a few live Douglas firs, alpine firs, and white pines. Briefly, restocking to the north of the seed group is only one-third complete and to the south and west is also insufficient.

The distances to which seed is dispersed are from 9 to 11 chains on the north to 5 to 6 on the south side of the seed trees. The dispersion for the greater distance in the northerly direction evidently is promoted by the prevailing wind and a more favorable aspect. White pine and Douglas fir seeded to a distance of 9 chains from the parent trees and white fir and western larch to 11 chains. Restocking in the northerly direction is also more regular than toward the south, in that it shows a gradual falling off in numbers

TABLE IV.—*Effective seed dispersion from groups of live trees, double burns of 1910 and 1919, 1923* [a]

| Species | Greatest distance of seed distribution from parent trees, and average number of seedlings per acre, by seed-tree groups and count strips | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Seed-tree Group A | | | | | | | | Seed-tree Group B [b] | | | |
| | NW. strip | | NE. strip | | SE. strip | | SW. strip | | NE. strip | | NW. strip | |
| | Distance | Seedlings | Distance | Seedlings | Distance | Seedlings | Distance | Seedlings | Distance | Seedlings | Distance | Seedlings |
| | *Chains* | *Number* | *Chains* | *Number* | *Chains* | *Number* | *Chains* | *Number* | *Chains* | *Number* | *Chains* | *Number* |
| Western white pine | 9 | 36 | 7 | 225 | 2 | 30 | 3 | 35 | | | 4 | 10 |
| White fir | 11 | 5 | 5 | 30 | | | | | 9 | 15 | 7 | 20 |
| Western larch | 11+ | 86 | 8+ | 70 | 1 | 12 | 5 | 40 | 8 | 5 | | |
| Douglas fir | 9 | 36 | 3 | 15 | | | | | 7 | 480 | 6 | 315 |
| Western hemlock | 7 | 14 | 3 | 5 | | | | | | | 6 | 25 |
| Lodgepole pine | 1 | 5 | 4 | 15 | 4 | 450 | 6 | 165 | | | | |
| Alpine fir | 2 | 9 | 2 | 180 | | | | | | | | |
| Total | | 191 | | 540 | | 492 | | 240 | | 500 | | 370 |
| | | *Per cent* | | *Per cent* | | *Per cent* | | *Per cent* | | *Per cent* | | *Per cent* |
| Western white pine | | 19 | | 42 | | 6 | | 15 | | 0 | | 3 |

| Species | Greatest distance of seed distribution from parent trees, and average number of seedlings per acre, by seed-tree groups and count strips | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Seed-tree Group C [c] | | | | Seed-tree Group D | | | | | |
| | NW. strip | | SE. strip | | NE. strip | | NW. strip | | SE. strip | |
| | Distance | Seedlings | Distance | Seedlings | Distance | Seedlings | Distance | Seedlings | Distance | Seedlings |
| | *Chains* | *Number* | *Chains* | *Number* | *Chains* | *Number* | *Chains* | *Number* | *Chains* | *Number* |
| Western white pine | 2 | 15 | 9 | 19 | 3 | 5 | 5 | 21 | 6 | 5 |
| White fir | 11 | 10 | | | 7 | 50 | 5 | 112 | 6 | 10 |
| Western larch | 7 | 40 | 8 | 31 | 5 | 45 | 9 | 75 | 8 | 15 |
| Douglas fir | 7 | 5 | | | 5 | 10 | 3 | 71 | 6 | 5 |
| Western hemlock | 7 | 30 | | | 5 | 35 | | | 6 | 25 |
| Total | | 100 | | 50 | | 145 | | 279 | | 60 |
| | | *Per cent* | | *Per cent* | | *Per cent* | | *Per cent* | | *Per cent* |
| Western white pine | | 15 | | 38 | | 3.4 | | 7.5 | | 8 |

[a] Slope varied for the different seed-tree groups and strips, as follows: Group A—NW. strip 25 to 50 per cent, NE. strip 25 to 30 per cent, SE. strip 20 to 30 per cent, SW. strip 30 to 55 per cent; Group B—30 to 50 per cent; Group C—NW. strip 10 to 25 per cent, SE. strip 25 to 35 per cent; Group D—NE. strip 30 to 50 per cent, NW. strip 20 to 35 per cent, SE. strip 0 to 20 per cent.

[b] No seedlings on southeast or southwest strips.

[c] No seedlings on northeast strip.

of seedlings per acre for given distances away from the parent trees. Many lodgepole seedlings occurred on the southerly strips, but these are not so much the result of dispersal from the seed groups as from the trees which existed in situ previous to the fires.

Another interesting seed group (marked *b* on the map and in Table IV) was found on a southerly spur at 4,000 feet elevation. This group consists of Douglas fir only, about 100 years old, rather short but of fairly good crown, and much deteriorated by the exposure resulting from fire. From this little group of a half-dozen trees count strips were run in four directions. The location of the group is such that the prevailing wind would carry the seed to a northwest aspect where chances of seedling survival would be better than on the south side.

In four years restocking to the northeast of the parent trees has taken place at the rate of 500 seedlings per acre; and to the northwest, 370 per acre, and this to a distance of 9 chains or less. There is absolutely no restocking to the southwest or southeast. Douglas fir seedlings predominate and show unmistakable relations to parent trees both in age and distribution; the white fir and the larch seedlings evidently came from trees which died during or shortly after the fire.

A third group of green seed trees (marked *c* on the map, and in Table IV) was found in a draw. This group consisted of five large white fir trees; four white pines, only one of which showed cones; three spruces, rather small but with many cones; and several small hemlocks. The location was such that seed dispersed toward the north and east would fall upon a very dry site. Count strips were run northwest and southeast from this group. The results are given under Group C in Table IV. Irregular restocking has taken place northwest and southeast to a distance of about 9 chains and none at all toward the northeast. What has come in is as yet insufficient, only 50 and 100 seedlings per acre.

A fourth group of seed trees, much larger and of older timber than any already described, occurs to the south (marked *d* on the map and in Table IV). The trees are western larch, western hemlock, white fir, Douglas fir, and a very few western white pines, all overmature and very tall. The seed from these trees would fall on the warm lower south slope toward the east and northeast, and on the terrace, or in the draw. Count strips were run in three directions to observe restocking toward the northwest, northeast, and southeast. The counts are given under Group D in Table IV.

Restocking from this group may be said to have only begun. The count shows 60 seedlings per acre toward the southeast, 145 toward the northeast, and 279 toward the northwest. Here, evidently, the rôle which aspect plays in the survival of seedlings is less pronounced than in the case of the previous seed groups. The ground is not as steep as it is at Groups B and C, and appears more favorable for seedling establishment.

## SINGLE BURNS OF 1910

### DEEP CREEK BURNS

An area of less than 160 acres on the northwest aspect near the mouth of Alder Creek was burned in 1910 but escaped the second (1919) fire. Here had been a full and overmature stand containing much splendid white pine, as well as larch, western hemlock, white fir, Douglas fir, and a small percentage of lodgepole pine, spruce, and alpine fir (pl. 4, A). The soil is deep and of good quality. The fire of 1910 left not one live tree on the entire area. It does not seem possible that any of these trees could have been the source of cones or seed subsequent to 1910, though a few may have had cones and seed at the time of the burn. On this area two long count strips were run diagonally down the slope toward the creek. The counts are given in Tables V and VI.

Table VI, for this northwest slope, shows 265 seedlings per acre, 37 per cent of which are western white pine—not a heavy stand, but a healthy and vigorous one. Table V classifies white pine in two age classes, one class from 8 to 13 years and a second at 4 years. For want of conclusive data, which could come only from consecutive examinations begun shortly after a fire and followed through for a number of years, the source of the seed can not be stated positively. The hypothesis that the seed was in the duff or on the burned trees may still hold. It is difficult to believe that the seed which gave rise to the older seedlings came from the outside, for the supply seems to have been cut short exactly five years after the 1910 fire. An outside source would presumably have been cut short nine years later by the 1919 fire.

Even more speculative is conjecture regarding the source of the 4-year-old white pine seedlings. Why 4 years, no

A. Near view of 1910 burn, Alder Creek. White-pine seedlings number 265 per acre, some of which may be seen in the foreground. The standing and down trees furnish some shade and shelter to the seedlings, which is very desirable. Unfortunately, the fire hazard is very great

B. Erosion in gully on lower part of north aspect, Alder Creek, burned hard in 1910 and 1919

TABLE V.—*Reproduction count, by age classes, single burn of 1910, Deep Creek, northwest aspect, 1923*

| Age class | All species | White pine |
|---|---|---|
| | *Per cent* | *Per cent* |
| 1 year | | |
| 2 years | 0.5 | |
| 3 years | 1.0 | |
| 4 years | 8.0 | 58.0 |
| 5 years | .5 | |
| 6 years | 1.5 | |
| 7 years | 3.5 | |
| 8 years | 18.0 | 30.3 |
| 9 years | 16.0 | 30.0 |
| 10 years | 30.0 | 43.7 |
| 11 years | 11.5 | 5.5 |
| 12 years | 3.5 | |
| 13 years | 6.0 | 20.0 |
| Total | 100.0 | 36.6 |

years old and older, and bears a relation in species to the former st... There are no new seedlings and no seeding is in progress. These areas were hard burned in 1910 and all the trees were killed. The nearest green trees on the windward side are one-half mile away. On the upper portion of the slope three western yellow pine seedlings were found, all growing in one spot. These were the only evidence of the species found on the Deep Creek area. Since the first fire much snow brush (*Ceanothus velutinus*) has taken hold, and considerable grass sod now covers from 80 to 90 per cent of the surface and is considered a hindrance to natural restocking. Reproduction counts of this slope are given in Table VI.

TABLE VI.—*Reproduction count, by species, single burn of 1910, Deep Creek, northwest and upper southwest aspects, 1923*

| Species | Northwest aspect | | | Upper southwest aspect | |
|---|---|---|---|---|---|
| | Former matured stand | Seedlings per acre | | Seedlings per acre | |
| | *Per cent* | *Number* | *Per cent* | *Number* | *Per cent* |
| Western white pine | 27.0 | 97 | 36.6 | 38 | 18.7 |
| White fir | 7.5 | 25 | 9.4 | 91 | 44.8 |
| Western larch | 1.5 | 88 | 33.2 | 3 | 1.5 |
| Douglas fir | 2.2 | 10 | 3.8 | 6 | 3.0 |
| Western hemlock | 39.0 | 37 | 14.0 | 23 | 11.3 |
| Lodgepole pine | 21.8 | 4 | 1.5 | 42 | 20.7 |
| Engelmann spruce | .5 | 4 | 1.5 | | |
| Alpine fir | .5 | | | | |
| Total | 100.0 | 265 | 100.0 | 203 | 100.0 |

more, no less? This takes us to 1919. Did the 1919 conflagration scatter seed? If so, it was distributed in advance of the fire, for no 4-year-olds appear on the double burn. As the 4-year-old seedlings were not so evident elsewhere on single burns, the source and dispersion of the seed which produced them must have been local rather than general. It seems reasonable to suppose that this seed was carried from green trees located in draws a half or a quarter of a mile to the south.

Observations and counts made in the 1910 burn on an upper southwest slope, Deep Creek, at elevations ranging from 4,300 to 4,500 feet, cover the area marked *e* on the map in Figure 1. In this area are two large patches on which the previous stand was 100 to 125 year old white pine, Douglas fir, lodgepole pine, lowland fir, and alpine fir. The natural reproduction is 8

### TRAIL CREEK BURNS

On the southwest corner of the large 1910 burn a spur terminating at the elbow of the Trail Creek was studied. This is almost cone shaped and more than 1,000 feet high. The principal slopes are generally northwest and northeast. (See fig. 2.) Previous to the 1910 burn there was an excellent stand of mature timber here which contained a high percentage of white pine. On the northeast slope the stand contained principally white pine, hemlock, and larch; and on the northwest white fir, Douglas fir, and scattered spruce and alpine fir in addition. All species, except some big larches on the lower part of the northeast aspect, were destroyed by the fire. Every part of the surface was burned. The soil is deep and of good quality, except on the upper northwest aspect and on the

ge which points toward the sharp bend of the creek. Three horizontal count strips were run on the northwest and three on the northeast slope, covering the upper, middle, and lower parts by separate tallies. The counts have been summarized in Tables VII and VIII.

Natural restocking is, in most cases, less than 200 seedlings to the acre, this number being exceeded on the lower northeast slope only. This is much poorer than anticipated. It is encouraging, however, to note that white pine shows a higher percentage in the reproduction over that of the previous stand.

The age classes of the seedlings show that the greater number are more than 7 years old, indicating that these older ones may have come from seed in the soil or duff. The better restocking found on the lower part of the northeast slope contains many seedlings from 1 to 4 years old. These appear where much typical vegetation such as accompanies white pine forests occurs, as species of Tiarella, Coptis, Asarum, etc., and where the soil is deeper and and more moist than on the southwest slopes.

Most of this seed came from green trees now extant on the flat toward the eastern portion of the area. The source of the miscellaneous younger seedlings found promiscuously over the area is most likely the old unburned forest to the southwest. Fresh and clean seed coats found underneath several 1-year old seedlings of white pine, hemlock, and Douglas fir point to dissemination of the seed by the wind and not storage in the soil. The exact relation of this dispersion of seed to green timber, has not been traced out, and as far as the strips were run toward this green timber no migration or relation was made evident.

TABLE VII.—*Reproduction count, by age classes, single burn of 1910, Trail Creek, northwest and northeast aspects, 1923*

| Age class | Northwest aspect—Seedlings per acre | | | | | | Northeast aspect—Seedlings per acre | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper slope | | Middle slope | | Lower slope | | Upper slope | | Middle slope | | Lower slope | |
| | *No.* | *Per ct.* | *No.* | *Per ct.* | *No.* | *Per ct.* | *No.* | *Per ct.* | *No.* | *Per ct.* | *No.* | *P. ct.* |
| 1 year | | | | | 3 | 1.5 | | | 3 | 2.0 | 33 | 3.0 |
| 2 years | 3 | 4.0 | 1 | 1.0 | 3 | 1.5 | 1 | 0.5 | 8 | 5.0 | 60 | 5.0 |
| 3 years | 4 | 5.0 | 3 | 2.0 | 1 | .5 | 2 | 1.0 | 1 | .5 | 6 | 1.0 |
| 4 years | 7 | 8.0 | 9 | 7.0 | 20 | 11.0 | 10 | 5.0 | 11 | 8.0 | 73 | 7.0 |
| 5 years | 1 | 1.0 | 5 | 4.0 | | | 2 | 1.0 | 5 | 3.5 | 60 | 5.0 |
| 6 years | 3 | 4.0 | 2 | 1.0 | 13 | 7.0 | 1 | .5 | 15 | 10.0 | 40 | 4.0 |
| 7 years | 17 | 20.0 | 4 | 3.0 | 14 | 8.0 | 2 | 1.0 | 15 | 10.0 | 180 | 16.0 |
| 8 years | 31 | 37.0 | 25 | 19.0 | 29 | 16.0 | 19 | 9.0 | 25 | 17.0 | 200 | 18.0 |
| 9 years | 7 | 8.0 | 20 | 15.0 | 24 | 13.0 | 21 | 10.0 | 9 | 6.0 | 155 | 14.0 |
| 10 years | 4 | 5.0 | 9 | 7.0 | 17 | 9.0 | 26 | 12.0 | 21 | 14.0 | 173 | 15.0 |
| 11 years | 5 | 6.0 | 10 | 8.0 | 10 | 6.0 | 27 | 12.0 | 14 | 10.0 | 60 | 5.0 |
| 12 years | 2 | 2.0 | 3 | 2.0 | 1 | .5 | 17 | 8.0 | 3 | 2.0 | 27 | 2.0 |
| 13 years | | | 1 | 1.0 | | | 4 | 2.0 | | | | |
| Unclassified | | | 39 | 30.0 | 46 | 26.0 | 81 | 38.0 | 17 | 12.0 | 53 | 5.0 |
| Total | 84 | 100.0 | 131 | 100.0 | 181 | 100.0 | 213 | 100.0 | 147 | 100.0 | 1,120 | 100.0 |

TABLE VIII.—*Reproduction count by species, single burn of 1910, Trail Creek, northwest and northeast aspects, 1923* [1]

| Species | Percentages of seedlings and dead trees, NW aspect | | | | | Percentages of seedlings and dead trees, NE aspect | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Upper slope | Middle slope | Lower slope | Average | Dead trees | Upper slope | Middle slope | Lower slope | Average | Dead trees |
| Western white pine | 44 | 50 | 63 | 52 | 26 | 50 | 50 | 32 | 44 | 28 |
| White fir | 6 | 13 | 4 | 8 | 7 | 6 | 11 | 5 | 7 | 10 |
| Western larch | 1 | 4 | 3 | 3 | 1 | 5 | 4 | 8 | 6 | 2 |
| Douglas fir | 1 | 2 | 1 | 1 | 5 | 2 | 4 | 17 | 8 | 3 |
| Western hemlock | 29 | 18 | 24 | 24 | 51 | 29 | 28 | 25 | 27 | 53 |
| Lodgepole pine | 15 | 11 | 2 | 9 | 1 | 3 | 3 | 12 | 6 | |
| Engelmann spruce | 4 | 2 | 3 | 3 | 9 | 4 | | 1 | 2 | |
| Alpine fir | | | 1 | | | 1 | | | | 2 |

[1] Percentages are given to nearest unit; total is thus not always an even 100 per cent.

It was, however, definitely shown on the northwest slope that a great many more seedlings of the older age classes existed on the minor northerly exposures, such as occur near draws, than on the general west or southwest aspects, and that on such northerly aspects much of the typical forest flora which is seen under the virgin forest has survived. This indicates clearly that there was abatement of the intensity of the burn, with less damage to soil and site conditions on the protected than on the exposed aspect, an important factor in restocking from seed in the duff.

An upper northwest and west aspect in the 1910 burn at an elevation of over 4,000 feet, and above the three lower strips, was also examined. Before 1910 this had been mainly a Douglas fir type, such as is often found on steep upper aspects in Idaho and western Montana. All of the trees had been killed outright in 1910. From both the count strips and general observation, it was concluded that this area neither has been nor is now restocking. Only a few lodgepole pine seedlings were found. The reasons could be sought in absence of seed, as well as in exposed site with extreme drought and heat in summer, or in heavy sod competition. It seems reasonable to suppose that all of these factors are here strong hindrances to natural restocking.

## DOUBLE BURN OF 1870 AND 1910

About 1 mile west from Magee Ranger Station is the area already mentioned that was burned hard about 1870 and again in 1910. This is a point of land between Trail Creek on the south and Bear Creek on the east, rising from 3,000 to 3,500 feet and more in elevation, broken to the south by several sharp draws, and many steep, bare, or grassy south slopes. (See fig. 3.) Previous to 1870 there was a dense overmature stand of the usual mixture of white pine, white fir, western larch, Douglas fir, etc., the Douglas fir being most prominent on the southerly aspect, the larch and lodgepole pine on the tops and white pine, white fir, and hemlock on protected aspects. On this area count strips were located according to aspects as shown by the dotted lines in Figure 3. The map shows the approximate location of green trees as well as the position and direction of the count strips.

After the first fire natural reproduction was generally good, even on the south and west aspects, and the resulting young stand, which was killed in 1910, contained much white pine.

As a result of the 1910 burn, this area presents three major and distinct field conditions induced by differences in topography, with the character and age of the forest approximately uniform for all three. Discussion of reproduction can well be divided accordingly into northerly aspects, southerly aspects, and tops and benches. On account of the lateness of the season, the reproduction studies on the higher points were not completed.

### NORTH AND EAST ASPECTS

Tables IX and X under strip A present data from a strip run in a northeast direction from the top of the spur (point *a* fig. 3) down into the draw, a distance of 5 chains. The purpose was to find out what reproduction had taken place where no seed trees had been either before or after the 1910 burn. Previous to 1910 a dense and thrifty young stand of white pine, western larch, Douglas fir, and white fir had come up here. Practically all of these were down in 1923.

Table X shows a total of 280 seedlings per acre, of which 50 per cent are white pine. There are practically no seedlings younger than 7 years. The distributions of the seedlings do not show any relation or order which would indicate the source of the seed or the migration. There are no live trees immediately to the south and west and no indications of seed dispersion.

A second and even more representative north aspect of this double burn is that covered by strips *b* and *c*, Figure 3, a steep slope where all trees but a few big larches were killed in 1870. These survivors and the young, thrifty 40-year stand surrounding them were all killed in 1910. Reproduction counts are given under strip *b* and strip *c* in Tables IX and X.

Observations at strip *b* show a total of 1,313 seedlings per acre, with 23 per cent white pine; and at strip *c* 535 seedlings per acre, of which 33 per cent are white pine. Seeding both of white pine and the other species appears from the distribution by age classes to have been in progress ever since the 1910 fire, and it is now impossible to know which of these sprang from seed in the duff and which did not. At any rate, the restocking and the condition of the soil and site after two bad fires are very gratifying.

TABLE IX.—*Reproduction count by age classes, double burns of 1870 and 1910, three strips, northerly aspect, 1923* [a]

| Age class | Strip A—Seedlings per acre | | Strip B—Seedlings per acre | | Strip C—Seedlings per acre | |
|---|---|---|---|---|---|---|
| | *Number* | *Per cent* | *Number* | *Per cent* | *Number* | *Per cent* |
| 1 year | | | 14 | 1 | | |
| 2 years | | | 19 | 1 | | |
| 3 years | | | 24 | 2 | 11 | 2 |
| 4 years | 20 | 7 | 38 | 3 | 35 | 7 |
| 5 years | | | 67 | 5 | 30 | 6 |
| 6 years | | | 100 | 8 | 65 | 12 |
| 7 years | 80 | 28 | 138 | 10 | 35 | 7 |
| 8 years | 60 | 22 | 180 | 14 | 41 | 7 |
| 9 years | 20 | 7 | 104 | 8 | 47 | 9 |
| 10 years | 60 | 22 | 156 | 12 | 18 | 3 |
| 11 years | | | 152 | 11 | 70 | 13 |
| 12 years | | | 73 | 6 | 30 | 6 |
| 13 years | 40 | 14 | 73 | 6 | 12 | 2 |
| Unclassified | | | 175 | 13 | 141 | 26 |
| Total | 280 | 100 | 1,313 | 100 | 535 | 100 |

[a] Percentages are rounded off to nearest unit.

TABLE X.—*Reproduction count by species, double burns of 1870 and 1910, three strips, northerly aspect, 1923* [a]

| Species | Strip A—Seedlings per acre | | Strip B—Seedlings per acre | | Strip C—Seedlings per acre | |
|---|---|---|---|---|---|---|
| | *Number* | *Per cent* | *Number* | *Per cent* | *Number* | *Per cent* |
| Western white pine | 140 | 50 | 305 | 23 | 176 | 33 |
| White fir | 40 | 14 | 85 | 7 | 41 | 7 |
| Western larch | | | 315 | 24 | 29 | 5 |
| Douglas fir | 60 | 22 | 33 | 3 | 24 | 5 |
| Western hemlock | 20 | 7 | 343 | 26 | 106 | 20 |
| Lodgepole pine | 20 | 7 | 175 | 13 | 135 | 25 |
| Engelmann spruce | | | 57 | 4 | 24 | 5 |
| Alpine fir | | | | | | |
| Total | 280 | 100 | 1,313 | 100 | 535 | 100 |

[a] Percentages have been rounded off to the nearest unit.

SOUTH AND WEST ASPECTS

The figures for the south and west aspects on this double 1870 and 1910 burn tell quite another story. Tables XI and XII, which summarize data for strip *d*, show only 58 seedlings per acre. Only 12 per cent of these are white pine, while 54 per cent are lodgepole pine; and practically no seedlings are younger than seven years. Three other separate observations on these steep south and west lower slopes at *e*, *f*, and *g* show no reproduction except a few lodgepole pines. These bare aspects are typical of many other similar areas in the Magee district. They are the result of hard double burns, and are characterized by thin, rocky soil, much sod, grass, and patches of snow brush. In some cases Douglas fir trees, either singly or in groups, have survived the two burns, but they have not given rise to any stocking whatever. Natural reproduction here during 13 years has been practically nil. The double burns have, therefore, brought about these permanent sores—sites extremely difficult to reforest, either naturally or artificially. We may assume that similar unfortunate conditions will follow on the steep south and west aspect on Deep Creek and Jordan Creek.

TABLE XI.—*Reproduction count by species, double burns of 1870 and 1910, southerly aspect, 1923*

| Species | Seedlings per acre. | |
|---|---|---|
| | *Number* | *Per cent* |
| Western white pine | 7 | 12 |
| White fir | 7 | 12 |
| Western larch | 3 | 5 |
| Douglas fir | 10 | 17 |
| Lodgepole pine | 31 | 54 |
| Total | 58 | 100 |

TABLE XII.—*Reproduction count by age classes, double burns of 1870 and 1910, southerly aspect, 1923*

| Age class | Seedlings per acre | White pine |
|---|---|---|
| | *Number* | *Per cent* |
| 1 year | | |
| 2 years | | |
| 3 years | | |
| 4 years | 3 | 100 |
| 5 years | | |
| 6 years | | |
| 7 years | 7 | 57 |
| 8 years | 3 | |
| 9 years | 7 | |
| 10 years | 14 | |
| 11 years | 14 | |
| 12 years | 7 | |
| 13 years | 3 | |
| Total | 58 | 12 |

TOPS AND BENCHES

Studies of natural reproduction on the tops and ridges throughout the Deep Creek area indicate restocking chiefly to lodgepole pine. One tally shows the following per acre:

| | Total per acre | Per cent |
|---|---|---|
| WWP | 77 | 7.7 |
| WF | 38 | 3.8 |
| WL | 69 | 6.9 |
| DF | 15 | 1.5 |
| WH | 31 | 3.1 |
| LPP | 770 | 77.0 |
| Total | 1,000 | 100 |

This shows a large predominance of lodgepole pine, but a few white pine seedlings appear here and there underneath the lodgepole saplings. The ages are in general 7 to 13 years, indicating little or extremely scant seed dispersion during the last five years.

A study of the migration of western larch toward the south and southwest from a group of green western larch at *j* on the top of the ridge shows effective seed dispersion to a distance of 8 chains from the live trees following the 1910 burn, with a total of 870 seedlings per acre, 6 per cent of which are white pine and 55 per cent western larch. The ages of the larch seedlings range from 1 to 13 years. This phase of the study was not completed for the 1870 and 1910 burns.

DOUBLE BURN 1889 AND 1910

UPPER SOUTH AND WEST ASPECTS

The reproduction study of this area is far from complete. The work done has, however, helped to clear up certain points as to the origin of the present conditions and the causes responsible for similar results elsewhere.

On the upper south and west aspects along the Idaho-Montana Divide occurred two very hard burns in 1889 and 1910. The first, which resulted from the "Chloride boom" near Pend Oreille Lake, appears to have crossed the divide from the Montana side and to have met the prevailing wind and stopped in the dense forest at an elevation of about 4,000 feet. The 1910 fire approached with considerable speed from the south and west, destroyed the splendid reproduction which had started since 1889, and crossed the divide into Montana.

This double burn is interesting, both from the standpoint of reproduction and of succession, in that barely enough time elapsed for seed production on the young stand before the second fire and also because of a widespread growth of dense snow brush.

Previous to the 1889 fire there was a mature and well-developed stand here, chiefly western larch and Douglas fir, with some white pine and white fir. Douglas fir showed up strongest on the dry sites. Some of these firs and a few of the larches have survived both fires and now remain as small scattered groups or isolated single trees, but entirely too few to restock the area adequately.

A tally made on an area of 1.56 acres gave the following data per acre:

| | Seedlings | Per cent |
|---|---|---|
| WWP | 4.5 | 15 |
| WF | 3.5 | 12 |
| WL | 13 | 45 |
| DF | 4 | 14 |
| WH | 2 | 7 |
| LPP | 2 | 7 |
| ES | 0 | 0 |
| AF | 0 | 0 |
| Total | 29 | 100 |

A total of 29 seedlings per acre gave 15 per cent white pine. These pines were from 8 to 12 years old, and were

underneath the spread of the limbs and among the dense ceanothus and willow brush. They seemed healthy, though not vigorous, and showed promise of survival and growth. Evidently on this warm, dry site the shrubbery is to them a help rather than a hindrance. No seeding appeared to have taken place in the last 5 years.

The finding of these seedlings here was a matter of much encouragement in that they indicate the probability that these brushy areas will eventually come back into forest. It will be about 30 years, however, before those already established begin to seed effectively. After that, natural restocking should be complete in about 20 years. Thus these two burns retarded the establishment of a complete new stand for at least 50 years.

## AGES OF WHITE PINE SEEDLINGS FOUND ON 1910 BURNS

A closer analysis of the time and manner of restocking of western white pine can best be made from the data obtained on the various 1910 burns. Study shows, in most cases, an active germination during the third, fourth, fifth, and sixth years, followed by an irregular germination in other years. In no instance has the germination of western white pine been pronounced during the first two years following the burn. White pine germination began in earnest in 1913, three years after the fire. This first active period culminated in 1915 on the 1870 and 1910 burn; in 1916 or 1917 on Alder Creek [2], and in 1917 and 1918 on the Trail Creek areas.

It may occasion surprise, but investigations indicate that western white pine seed may remain viable in the ground for five and six years following a burn. In 1914 white pine seed was recovered from duff underneath a 150-year-old stand on Big Creek, Kaniksu National Forest. These seeds were placed immediately in the greenhouse under conditions favorable for germination. The first germination was about 18 months later. Seeds which require 18 months of favorable temperature conditions before germination in the greenhouse might well require four or five seasons under unfavorable germinating conditions in the field.

The second period of germination showed up very strong only on the 1870 and 1910 double burn on Trail Creek. The seed in this case could well have come from trees located from one-half to one mile away to windward. The germination in 1920 on Alder Creek shows a separate and subsequent seeding. Presumably the seed did not come very far or similar conditions would have been found elsewhere. The inference is that the seed was distributed during the fall of 1919, either during or after the big fire, and that the green trees about one-half mile to the south furnished the seed.

Considering only the germination on the single 1910 burns on Trail Creek, there is a more or less sustained restocking on both the exposed and the protected aspects. In most cases this shows a fair germination in 1920, poor in 1921, rising again in 1922, and lowering in 1923. Since there are no green trees of white pine which furnish seed, closer than one-half mile, and as these seedlings appeared promiscuously over the area without reference to the character of the surface, no other deduction seems possible than that here a long range seeding is in progress.

## EROSION AND SITE DETERIORATION

Except for steep south slopes, leaching and site deterioration are negligible, or at least are not a factor to be concerned over. Certain deep gullies have been cut on the lower north slope on Alder Creek (pl. IV, B). Here the head gathered by the water, presumably at the time of most rapid snow melting in spring, has cut gullies extending 500 to 600 feet up the slope. Soil, as well as rock, is carried down these gullies into Alder Creek bottom, where the bowlders remain while the finer particles are carried away.

Steep south slopes, however, present a serious situation. Here the burns are so destructive to all vegetation and roots that finer particles of the soil leach out or wash away, leaving a surface covering of fine angular rock and gravel which becomes very hot and very dry in the summer, so much so that natural seedlings, when these do come up, succumb to drought shortly after germination. Even artificial reforestation on such sites is very difficult.

### VEGETATION

The following observations are briefly the more outstanding conclusions regarding some phases of succession of

[2] On the Alder Creek area it is not absolutely certain that no germination took place in 1917; there were some seedlings the ages of which were doubtful.

vegetation on different burns. From the 1923 study it appears that the vegetation which has followed the single and double fires on the Deep Creek and Trail Creek areas is but a scanty growth and as such is a benefit rather than a detriment to natural restocking. On severe double burns a definite cycle of succession is evident. It begins with light-seeded willow, everlasting fireweed, goldenrod, and thistle. This series runs its course during the first decade and is then crowded out by snow brush, goat brush, maple, juneberry, huckleberry, ocean spray, ninebark, thimbleberry, snowberry, elderberry, and cherry. Some of these seed in directly after the burn, others spring from sprouts, and still others are seeded in later by birds.

On moist sites much of the original forest vegetation—which includes Coptis, Tiarella, Pyrola, Claytonia, Linnaea, and various ferns and herbaceous plants—takes direct possession of the ground. Evidently the fire in such cases has not burned deeply enough to kill the roots or the seeds. This type of vegetation is always more in evidence on single than on double burns.

The above conditions hold generally for north slopes, high benches, and gentle south and west aspects. On steep south and west slopes, however, the succession is quite different. The lower portions, which become very dry and warm, show a strong tendency toward formation of sod. While this retards erosion, it is thought to deter natural reproduction. Such sites are very dry in midsummer, and the many herbs and shrubs which occur elsewhere and which would be very beneficial as soil builders, checks to erosion, and in furnishing shelter to seedlings, are wanting. The upper south slopes and knolls become, by repeated fires, almost a pure snow brush type. This snow brush is sometimes present before the fire, and sprouts profusely afterwards. It frequently seeds in directly after or during the fire. When the second burn occurs the brush takes almost complete possession by rapid sprouting, as its stout and deep roots have escaped injury. This brush cover later yields its place to the forest, but in the early life of the stand it nurses and protects the scattered young seedlings.

From the standpoint of grazing, these burns must be a distinct disappointment. The vegetation is of poor quality and rather sparse. The sheep would have to travel too much to find sufficient forage. In this respect both the single and the double burns of 1910 and 1919 on the Coeur d'Alene National Forest fall far below the Clearwater National Forest. On the latter, many of the double burns are followed by a wealth of high and dense vegetation which often hinders natural restocking. The profuse and palatable wild pea and the hollyhock, so abundant on the Clearwater Forest, are much less evident on the Coeur d'Alene.

Species of Ribes, which would act as carriers in the event of an invasion of the blister rust disease, occur over the Coeur d'Alene burns, but these are chiefly confined to the watercourses and are generally few and far between on the slopes.

## SUMMARY AND CONCLUSIONS

Through analysis of the natural restocking on singly and doubly burned areas on the headwaters of the Coeur d'Alene River in northern Idaho, certain conclusions seem to be warranted. In every instance where a single fire destroyed a mature forest, as in the fires of 1870, 1889, and 1910, the natural restocking of the forest has been prompt, uniform, and complete, and western white pine has made up a goodly proportion of the reproduction. In the case of double burns, however, as instanced by that of 1910 and 1919, restocking is woefully deficient.

The time interval between a first and a second fire greatly influences results, for if fire covers the area a second time before any of the young growth has produced seed, the chances of natural reproduction are much reduced. An area burned in 1870 and again in 1910 showed very good restocking, except on lower south and west aspects. The young forest, which was 35 to 40 years old when destroyed in 1910, had produced seed which evidently helped to restock the area after the 1910 fire. The failure of reproduction on the exposed aspects must be considered as directly due to the action of the two fires in reducing the quality of the site, and in causing extreme and critical conditions for natural reestablishment.

Such double burns, occurring at intervals up to seeding age of the young trees, are followed by heavy grass sod on lower south slopes and dense mats of snow brush on the upper south and west. The grass is considered a hindrance, and the snow brush a help, in natural restocking. Large areas which burned in 1889 and again in 1910 contain scattered seedlings which are nursed along on a very critical site by the prevalent brush.

The outstanding and most extensive double burn of 1910 and 1919 on the Deep Creek area showed very scant new reproduction—from one to two new seedlings per acre on protected north and east aspects, and one or none on exposed aspects. There is much western larch reseeding on northerly aspects from parent trees which survived one or both of these fires. Numerous groups of seedlings 8 to 13 years old occur in patches over this double burn, but only where the force and sweep of the last fire was less intense. After a period of about 20 years these groups should produce seed, which will aid in restocking the double burns. Several groups of mature trees were also found to have survived the two severe fires. These exist either on sharp knolls, on rocky spurs, or in deep draws. They are now supplying seed for restocking of the double burn at distances up to 9 and 11 chains, mainly toward the north and east, in the direction of the prevailing wind.

Close examination of the ages of white pine seedlings found on the various 1910 burns shows that very little germination takes place during the first and second year after the fire, and that the greatest number of white pine seedlings have become established during the fourth, fifth, and sixth years following the burn, probably from seed buried in the soil by rodents previous to the fire. Later seeding is much less, in some years almost nothing, and is evidently due to distribution of the seed, in some cases for distances of one or more miles. An effort to correlate this later seeding with seed crops has not brought positive results, mainly because there is too much uncertainty regarding the local seed production in past seasons.

Both the character and the scantiness of the vegetation observed on the large double burns of 1910 and 1919 indicate very poor grazing values. In most places the vegetation is a help rather than a hindrance to natural reforestation.

Subsequent to the large double burns of 1910 and 1919 there was but slight erosion, which took the form of deep gullying on lower north slopes. The most serious site deterioration was on the steep lower south aspects in the form of leaching or washing away of the finer loam and soil particles, leaving a relatively large proportion of rock and gravel and causing extremes of surface drought and heat detrimental to natural restocking.

On the basis of these and previous studies, as well as from general observation over a period of years, it is believed that there need be no concern about natural restocking after single burns in northern Idaho where forests of seed-bearing age are destroyed. Only one instance of failure of natural restocking has been found thus far namely, on the south aspect of Johnigan Mountain on the Clearwater National Forest. There is, therefore, no necessity for artificial reforestation on single burns in northern Idaho. The situation on large double burns, however, such as those of 1910 and 1919, clamors for thought and action. It would seem to be well to confine all efforts of planting to south and west slopes, in order to get the plants established before the site has deteriorated so far as to render artificial restocking difficult.

The distribution of seed from groups of seed trees is directly applicable in silviculture, for it can safely be assumed that seed dispersal on cut-over areas will be more uniform and effective than that shown on burns, mainly because the physical conditions of the site on logged areas are much less critical for seedlings than are conditions on double burns.

The data on restocking from seed already on the forest floor at the time of the fire are not altogether safe to apply. We need to know more about the source of the seed which gives rise to the first cycle of reproduction on burns, and this can be determined only by the installation of permanent sample plots on fresh and large burns. In the application of the results to cutting practice, the point should be kept in mind that fires in virgin timber burn under different conditions than those on logged land. On logged land there is greater concentration of heat and more complete consumption of duff and other surface material than when virgin forests burn. It may be said, however, that indications are very strong, from the study of both logged and burned areas in the western white pine forests, that the seed which gives rise to the first cycle of natural reproduction is already in the duff at the time the mature seed trees are removed; but this can be proved only by the study of permanent sample plots

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